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· THE
STEREOSCOPE.

ITS HISTORY, THEORY, AND CONSTRUCTION

**WITH ITS APPLICATION TO THE FINE AND USEFUL ARTS
AND TO EDUCATION.**

BY

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ON THE STEREOSCOPE.

INTRODUCTION.

THE *Stereoscope*, a word derived from *στέρεος*, *solid*, and *σκοπεῖν*, to *see*, is an optical instrument, of modern invention, for representing, in apparent relief and solidity, all natural objects and all groups or combinations of objects, by uniting into one image two plane representations of these objects or groups as seen by each eye separately. In its most general form the Stereoscope is a *binocular* instrument, that is, is applied to *both* eyes; but in two of its forms it is *monocular*, or applied only to *one* eye, though the use of the other eye, without any instrumental aid, is necessary in the combination of the two plane pictures, or of one plane picture and its reflected image. The Stereoscope, therefore, cannot, like the telescope and microscope, be used by persons who have lost the use of one eye, and its remarkable effects cannot be properly appreciated by those whose eyes are not equally good.

When the artist represents living objects, or groups of them, and delineates buildings or landscapes, or when he

copies from statues or models, he produces apparent solidity, and difference of distance from the eye, by light and shade, by the diminished size of known objects as regulated by the principles of geometrical perspective, and by those variations in distinctness and colour which constitute what has been called aerial perspective. But when all these appliances have been used in the most skilful manner, and art has exhausted its powers, we seldom, if ever, mistake the plane picture for the solid which it represents. The two eyes scan its surface, and by their distance-giving power indicate to the observer that every point of the picture is nearly at the same distance from his eye. But if the observer closes one eye, and thus deprives himself of the power of determining differences of distance by the convergency of the optical axes, the relief of the picture is increased. When the pictures are truthful photographs, in which the variations of light and shade are perfectly represented, a very considerable degree of relief and solidity is thus obtained ; and when we have practised for a while this species of monocular vision, the drawing, whether it be of a statue, a living figure, or a building, will appear to rise in its different parts from the canvas, though only to a limited extent.

In these observations we refer chiefly to ordinary drawings held in the hand, or to portraits and landscapes hung in rooms and galleries, where the proximity of the observer, and lights from various directions, reveal the surface of the paper or the canvas ; for in panoramic and dioramic representations, where the light, concealed from the observer, is introduced in an oblique direction, and where the distance of the picture is such that the convergency of the

optic axes loses much of its distance-giving power, the illusion is very perfect, especially when aided by correct geometrical and aerial perspective. But when the panorama is illuminated by light from various directions, and the slightest motion imparted to the canvas, its surface becomes distinctly visible, and the illusion instantly disappears.

The effects of stereoscopic representation are of a very different kind, and are produced by a very different cause. The singular relief which it imparts is independent of light and shade, and of geometrical as well as of aerial perspective. These important accessories, so necessary in the visual perception of the drawings *in plano*, avail nothing in the evolution of their *relievo*, or third dimension. They add, doubtless, to the beauty of the binocular pictures ; but the stereoscopic creation is due solely to the superposition of the two plane pictures by the optical apparatus employed, and to the distinct and instantaneous perception of distance by the convergency of the optic axes upon the similar points of the two pictures which the stereoscope has united.

If we close one eye while looking at photographic pictures in the stereoscope, the perception of relief is still considerable, and approximates to the binocular representation ; but when the pictures are mere diagrams consisting of white lines upon a black ground, or black lines upon a white ground, the relief is instantly lost by the shutting of the eye, and it is only with such binocular pictures that we see the true power of the stereoscope.

As an amusing and useful instrument the stereoscope derives much of its value from photography. The most

skilful artist would have been incapable of delineating two equal representations of a figure or a landscape as seen by two eyes, or as viewed from two different points of sight ; but the binocular camera, when rightly constructed, enables us to produce and to multiply photographically the pictures which we require, with all the perfection of that interesting art. With this instrument, indeed, even before the invention of the Daguerreotype and the Talbotype, we might have exhibited temporarily upon ground glass, or suspended in the air, the most perfect stereoscopic creations, by placing a Stereoscope behind the two dissimilar pictures formed by the camera.

CHAPTER I.

HISTORY OF THE STEREOSCOPE.

WHEN we look with both eyes open at a sphere, or any other solid object, we see it by uniting into one two pictures, one as seen by the right, and the other as seen by the left eye. If we hold up a thin book perpendicularly, and midway between both eyes, we see distinctly the back of it and both sides with the eyes open. When we shut the right eye we see with the left eye the back of the book and the left side of it, and when we shut the left eye we see with the right eye the back of it and the right side. The picture of the book, therefore, which we see with both eyes, consists of *two* dissimilar pictures united, namely, a picture of the back and the left side of the book as seen by the left eye, and a picture of the back and right side of the book as seen by the right eye.

In this experiment with the book, and in all cases where the object is near the eye, we not only see *different pictures* of the same object, but we see *different things* with each eye. Those who wear spectacles see only the left-hand spectacle-glass with the left eye, on the left side of the face, while with the right eye they see only the right-hand spectacle-glass on the right side of the face, both glasses of the spectacles being seen united midway

between the eyes, or above the nose, when both eyes are open. It is, therefore, a fact well known to every person of common sagacity that *the pictures of bodies seen by both eyes are formed by the union of two dissimilar pictures formed by each.*

This palpable truth was known and published by ancient mathematicians. Euclid knew it more than two thousand years ago, as may be seen in the 26th, 27th, and 28th theorems of his *Treatise on Optics*.¹ In these theorems he shews that the part of a sphere seen by both eyes, and having its diameter equal to, or greater or less than the distance between the eyes, is equal to, and greater or less than a hemisphere; and having previously shewn in the 23d and 24th theorems how to find the part of any sphere that is seen by one eye at different distances, it follows, from constructing his figure, that each eye sees different portions of the sphere, and that it is seen by both eyes by the union of these two dissimilar pictures.

More than *fifteen hundred* years ago, the celebrated physician Galen treated the subject of binocular vision more fully than Euclid. In the *twelfth* chapter of the tenth book of his work, *On the use of the different parts of the Human Body*, he has described with great minuteness the various phenomena which are seen when we look at bodies with both eyes, and alternately with the right and the left. He shews, by diagrams, that dissimilar pictures of a body are seen in each of these three modes of viewing it; and, after finishing his demonstration, he adds,—

“ But if any person does not understand these demonstra-

¹ Edit. of Pena, pp. 17, 18, Paris, 1577; or *Opera*, by Gregory, pp. 619, 620. Oxon. 1703.

tions by means of lines, he will finally give his assent to them when he has made the following experiment :— Standing near a column, and shutting each of the eyes in succession ;—when the *right* eye is shut, some of those parts of the column which were previously seen by the *right* eye on the *right* side of the column, will not now be seen by the *left* eye ; and when the *left* eye is shut, some of those parts which were formerly seen by the *left* eye on the *left* side of the column, will not now be seen by the *right* eye. But when we, at the same time, open both eyes, both these will be seen, for a greater part is concealed when we look with either of the two eyes, than when we look with both at the same time.”¹

In such distinct and unambiguous terms, intelligible to the meanest capacity, does this illustrious writer announce the fundamental law of binocular vision—the grand principle of the Stereoscope, namely, that *the picture of the solid column which we see with both eyes is composed of two dissimilar pictures, as seen by each eye separately*. As the vision of the solid column, therefore, was obtained by the union of these dissimilar pictures, an instrument only was wanted to take such pictures, and another to combine them. The Binocular Photographic Camera was the one instrument, and the Stereoscope the other.

The subject of binocular vision was studied by various optical writers who have flourished since the time of Galen. Baptista Porta, one of the most eminent of them, repeats, in his work *On Refraction*, the propositions of Euclid on the vision of a sphere with one and both eyes, and he cites from Galen the very passage which we have given

¹ *De Usu Partium Corporis Humani*, edit. Lugduni, 1550, p. 593.

above on the dissimilarity of the three pictures seen by each eye and by both. Believing that we see only with one eye at a time, he denies the accuracy of Euclid's theorems, and while he admits the correctness of the observations of Galen, he endeavours to explain them upon other principles.

In illustrating the views of Galen on the dissimilarity of the three pictures which are requisite in binocular vision, he employs a much more distinct diagram than that which is given by the Greek physician. "Let A," he says, "be the

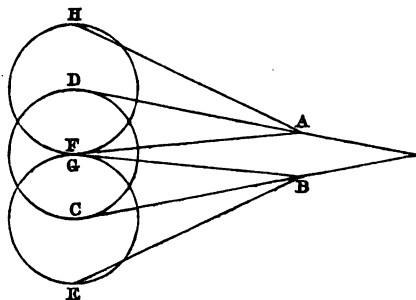


FIG. 1.

pupil of the right eye, B that of the left, and DC the body to be seen. When we look at the object with both eyes we see DC, while with the left eye we see EF, and with the right eye GH. But if it is seen with one eye, it will be seen otherwise, for when the left eye B is shut, the body CD, on the left side, will be seen in HG; but when the right eye is shut, the body CD will be seen in FE, whereas, when both eyes are opened at the same time, it will be seen in CD." These results are then explained by copying the passage

from Galen, in which he supposes the observer to repeat these experiments when he is looking at a solid column.

In looking at this diagram, we recognise at once not only the principle, but the construction of the stereoscope. The double stereoscopic picture or slide is represented by HE; the right-hand picture, or the one seen by the right eye, by HF; the left-hand picture, or the one seen by the left eye, by GE; and the picture of the solid column in full relief by DC, as produced midway between the other two dissimilar pictures, HF and GE, by their union, precisely as in the stereoscope.¹

Galen, therefore, and the Neapolitan philosopher, who has employed a more distinct diagram, certainly knew and adopted the fundamental principle of the stereoscope; and nothing more was required, for producing pictures in full relief, than a simple instrument for uniting HF and GE, the right and left hand dissimilar pictures of the column.

In the treatise on painting which he left behind him in MS.,² Leonardo da Vinci has made a distinct reference to the dissimilarity of the pictures seen by each eye as the reason why "a painting, though conducted with the greatest art, and finished to the last perfection, both with regard to its contours, its lights, its shadows, and its colours, can never shew a *relievo* equal to that of the natural objects, unless these be viewed at a distance and with a single eye,"³ which he thus demonstrates. "If an object *c* be viewed by a single eye at *A*, all objects in the space behind it—included, as it were, in a shadow EOF, cast by

¹ Joan. Baptistæ Portæ Neap., *De Refractione Opticæ parte*, lib. v. p. 132, and lib. vi. pp. 143-5. Neap. 1593.

² *Trattato della Pittura, Scultura, ed Architettura*. Milan, 1584.

³ Dr. Smith's *Complete System of Opticks*, vol. ii., Remarks, pp. 41 and 244.

a candle at A—are invisible to an eye at A ; but when the other eye at B is opened, part of these objects become visible to it ; those only being hid from both eyes that

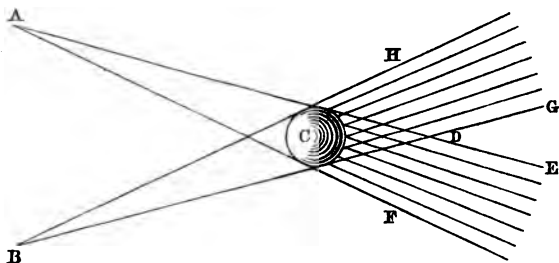


FIG. 2.

are included, as it were, in the double shadow CD, cast by two lights at A and B and terminated in D ; the angular space EDG, beyond D, being always visible to both eyes. And the hidden space CD is so much the shorter as the object c is smaller and nearer to the eyes. Thus he observes that the object c, seen with both eyes, becomes, as it were, transparent, according to the usual definition of a transparent thing, namely, that which hides nothing beyond it. But this cannot happen when an object, whose breadth is bigger than that of the pupil, is viewed by a single eye. The truth of this observation is, therefore, evident, because a painted figure intercepts all the space behind its apparent place, so as to preclude the eyes from the sight of every part of the imaginary ground behind it. Hence," continues Dr. Smith, " we have one help to distinguish the place of a near object more accurately *with both eyes than with one*, inasmuch as we see it more detached from other objects

beyond it, *and more of its own surface, especially if it be roundish.*"

We have quoted this passage, not from its *proving* that Leonardo da Vinci was acquainted with the fact that each eye, A, B, sees dissimilar pictures of the sphere c, but because it has been referred to by Mr. Wheatstone as the only remark on the subject of binocular vision which he could find "after looking over the works of many authors who might be expected to have made them." We think it quite clear, however, that the Italian artist knew as well as his commentator Dr. Smith, that each eye, A and B, sees dissimilar parts of the sphere c. It was not his purpose to treat of the binocular pictures of c, but his figure proves their dissimilarity.

The subject of binocular vision was successfully studied by Francis Aguillon or Aguilonius,¹ a learned Jesuit, who published his Optics in 1613. In the first book of his work, where he is treating of the vision of solids of all forms, (*de genere illorum quæ vâ origia (ta sterea) nuncupantur*), he has some difficulty in explaining, and fails to do it, why the two dissimilar pictures of a solid, seen by each eye, do not, when united, give a confused and imperfect view of it. This discussion is appended to the demonstration of the theorem, "that when an object is seen with two eyes, two optical pyramids are formed whose common base is the object itself, and whose vertices are in the eyes,"² and is as follows:—

"When one object is seen with two eyes, the angles at

¹ *Opticorum Libri Sex Philosophis juxta ac Mathematicis utiles*. Folio. Antverpiæ, 1613.

² In FIG. 1, AEF is the optical pyramid seen by the eye A, and BGF the optical pyramid seen by the eye B.

the vertices of the optical pyramids (namely, HAF, GBE, Fig. 1) are not always equal, for beside the direct view in which the pyramids ought to be equal, into whatever direction both eyes are turned, they receive pictures of the object under unequal angles, the greatest of which is that which is terminated at the nearer eye, and the lesser that which regards the remoter eye. This, I think, is perfectly evident; but I consider it as worthy of admiration, how it happens that bodies seen by both eyes are not all confused and shapeless, though we view them by the optical axes fixed on the bodies themselves. For greater bodies, seen under greater angles, appear lesser bodies under lesser angles. If, therefore, one and the same body which is in reality greater with one eye, is seen less on account of the inequality of the angles in which the pyramids are terminated, (namely, HAF, GBE,¹) the body itself must assuredly be seen greater or less at the same time, and to the same person that views it; and, therefore, since the images in each eye are dissimilar (*minime sibi congruunt*) the representation of the object must appear confused and disturbed (*confusa ac perturbata*) to the primary sense."

"This view of the subject," he continues, "is certainly consistent with reason, but, what is truly wonderful is, that it is not correct, for bodies are seen clearly and distinctly with both eyes when the optic axes are converged upon them. The reason of this, I think, is, that the bodies do not appear to be single, because the apparent images, which are formed from each of them in separate eyes, exactly coalesce, (*sibi mutuo exacte congruunt*), but because

¹ These angles are equal in this diagram and in the vision of a sphere, but they are unequal in other bodies.

the common sense imparts its aid equally to each eye, exerting its own power equally in the same manner as the eyes are converged by means of their optical axes. Whatever body, therefore, each eye sees with the eyes conjoined, the common sense makes a single notion, not composed of the two which belong to each eye, but belonging and accommodated to the imaginative faculty to which it (the common sense) assigns it. Though, therefore, the angles of the optical pyramids which proceed from the same object to the two eyes, viewing it obliquely, are unequal, and though the object appears greater to one eye and less to the other, yet the same difference does not pass into the primary sense if the vision is made only by the axes, as we have said, but if the axes are converged on this side or on the other side of the body, the image of the same body will be seen double, as we shall shew in Book iv., on the fallacies of vision, and the one image will appear greater and the other less on account of the inequality of the angles under which they are seen."¹

Such is Aguilonius's theory of binocular vision, and of the union of the two dissimilar pictures in each eye by which a solid body is seen. It is obviously more correct than that of Dr. Whewell and Mr. Wheatstone. Aguilonius affirms it to be contrary to reason that two dissimilar pictures can be united into a clear and distinct picture, as they are actually found to be, and he is therefore driven to call in the aid of what does not exist, a *common sense*, which rectifies the picture. Dr. Whewell and Mr. Wheatstone have cut the Gordian knot by maintaining what is impossible, that in binocular and stereoscopic vision a long line

¹ Aguilonius, *Opticorum*, lib. ii. book xxxviii. pp. 140, 141.

is made to coincide with a short one, and a large surface with a small one ; and in place of conceiving this to be done by a common sense overruling optical laws, as Aguilonius supposes, they give to the tender and pulpy retina, the recipient of ocular pictures, the strange power of contracting or expanding itself in order to equalize unequal lines and unequal surfaces !

In his fourth and very interesting book, on the fallacies of distance, magnitude, position, and figure, Aguilonius resumes the subject of the vision of solid bodies. He repeats the theorems of Euclid and Gassendi on the vision of the sphere, shewing how much of it is seen by each eye, and by both, whatever be the size of the sphere, and the distance of the observer. At the end of the theorems, in which he demonstrates that when the diameter of the sphere is equal to the distance between the eyes we see exactly a hemisphere, he gives the annexed drawing of the mode in which the sphere is seen by each eye, and by both.

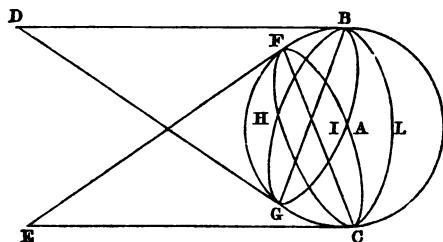


FIG. 3.

In this diagram E is the right eye and D the left, CHF I the section of that part of the sphere BC which is seen by the right eye E, BHGA the section of the part which is seen by the left eye D, and BLC the half of the great circle which is

the section of the sphere as seen by both eyes.¹ These three pictures of the solids are all dissimilar. The right eye *E* does not see the part *BLCIF* of the sphere; the left eye does not see the part *BLCGA*, while the part seen with both eyes is the hemisphere *BLOGF*, the dissimilar segments *BFG*, *CGF* being united in its vision.²

After demonstrating his theorems on the vision of spheres with one and both eyes,³ Aguilonius informs us, before he proceeds to the vision of cylinders, that it is agreed upon that it is not merely true with the sphere, but also with the cylinder, the cone, and all bodies whatever, that the part which is seen is comprehended by tangent rays, such as *EB*, *EC* for the right eye, in Fig. 3. "For," says he, "since these tangent lines are the outermost of all those which can be drawn to the proposed body from the same point, namely, that in which the eye is understood to be placed, it clearly follows that the part of the body which is seen must be contained by the rays touching it on all sides. For in this part no point can be found from which a right line cannot be drawn to the eye, by which the correct visible form is brought out."⁴

Optical writers who lived after the time of Aguilonius seem to have considered the subject of binocular vision as exhausted in his admirable work. Gassendi,⁵ though he treats the subject very slightly, and without any figures, tells us that we see the left side of the nose with the left

¹ It is obvious that a complete hemisphere is not seen with both eyes.

² Aguilonius, *Opticorum*, lib. iv. pp. 306, 307.

³ In the last of these theorems Aguilonius describes and explains, we believe for the first time, the *conversion of relief* in the vision of convex and concave surfaces. See Prop. xciv. p. 312.

⁴ Id., Id., p. 313.

⁵ *Opera*, tom. ii. p. 394. Lugduni, 1658.

eye, and the right side of it with the right eye,—two pictures sufficiently dissimilar. Andrew Tacquet,¹ though he quotes Aguilonius and Gassendi on the subject of seeing distances with both eyes, says nothing on the binocular vision of solids; and Smith, Harris, and Porterfield, only touch upon the subject incidentally. In commenting on the passage which we have already quoted from Leonardo da Vinci, Dr. Smith says, “Hence we have one help to distinguish the place of a near object more accurately with both eyes than with one, inasmuch as we see it more detached from other objects beyond it, *and more of its own surface, especially if it be roundish.*”² If any farther evidence were required that Dr. Smith was acquainted with the dissimilarity of the images of a solid seen by each eye, it will be found in his experiment with a “long ruler placed between the eyebrows, and extended directly forward with its flat sides, respecting the right hand and the left.” “By directing the eyes to a remote object,” he adds, “the *right side of the ruler seen by the right eye* will appear on the left hand, and *the left side on the right hand*, as represented in the figure.”³

In his Treatise on Optics, published in 1775, Mr. Harris, when speaking of the visible or apparent figures of objects, observes, that “we have other helps for distinguishing *prominences of small parts* besides those by which we distinguish distances in general, as their degrees of light and shade, and *the prospect we have round them.*” *And by the parallax, on account of the distance betwixt our eyes, we can distinguish besides the front part of the two sides of*

¹ *Opera Mathematica Optica*, tribus libris exposita, p. 136.

² *Opticks*, vol. ii., Remarks, pp. 41 and 245.

³ *Id.*, vol. i. p. 48, Fig. 106.

*a near object not thicker than the said distance, and this gives a visible relievio to such objects, which helps greatly to raise or detach them from the plane in which they lie. Thus the nose on a face is the more remarkably raised by our seeing both sides of it at once."*¹ *That is, the relievio is produced by the combination of the two dissimilar pictures given by each eye.*

Without referring to a figure given by Dr. Porterfield, in which he actually gives drawings of an object as seen by each eye in binocular vision,² the one exhibiting the object as seen endwise by the right eye, and the other the same object as seen laterally by the left eye, we may appeal to the experience of every optical, or even of every ordinary observer, in support of the fact, that the dissimilarity of the pictures in each eye, by which we see solid objects, is known to those who have never read it in Galen, Porta, or Aguilonius. Who has not observed the fact mentioned by Gassendi and Harris, that their left eye sees only the left side of their nose, and their right eye the right side, two pictures sufficiently dissimilar? Who has not noticed, as well as Dr. Smith, that when they look at any thin, flat body, such as a thin book, they see both sides of it—the *left eye only the left side of it, and the right eye only the right side*, while the back, or the part nearest the face, is seen by each eye, and both the sides and the back by both the eyes? What student of perspective is there—master or pupil, male or female—who does not know, as certainly as he knows his alphabet, that the picture of a chair or table, or anything else, drawn from *one point of sight*, or as

¹ *Treatise on Optics*, p. 171; see also sect. 64, p. 113.

² *Treatise on the Eye*, vol. i. p. 412, Plate 5, Fig. 37.

seen by one eye placed in that point, is *necessarily dissimilar* to another drawing of the same object taken from another point of sight, or as seen by the other eye placed in a point $2\frac{1}{2}$ inches distant from the first? If such a person is to be found, we might then admit that the dissimilarity of the pictures in each eye was not known to every student of perspective.¹

Such was the state of our knowledge of binocular vision when two individuals, Mr. Wheatstone, and Mr. Elliot, now Teacher of Mathematics in Edinburgh, were directing their attention to the subject. Mr. Wheatstone communicated an important paper on the Physiology of Vision to the British Association at Newcastle in August 1838, and exhibited an instrument called a Stereoscope, by which he united the two dissimilar pictures of solid bodies, the *τὰ στέρεα*, (*ta sterea* of Aguilonius,) and thus reproduced, as it were, the bodies themselves. Mr. Wheatstone's paper on the subject, which had been previously read at the Royal Society on the 21st of June, was printed in their Transactions for 1838.²

Mr. Elliot was led to the study of binocular vision in consequence of having written an Essay, so early as 1823, for the Class of Logic in the University of Edinburgh, "On the means by which we obtain our knowledge of distances by the Eye." Ever since that date he was familiar with the idea, that the relief of solid bodies seen by the eye was

¹ As Mr. Wheatstone himself describes the dissimilar pictures or drawings as "two different projections of the same object seen from *two points of sight*, the distance between which is equal to the interval between the eyes of the observer," it is inconceivable on what ground he could imagine himself to be the discoverer of so palpable and notorious a fact as that the pictures of a body seen by two eyes—*two points of sight*, must be dissimilar.

² *Phil. Trans.*, 1838, pp. 371-394.

produced by the union of the dissimilar pictures of them in each eye, but he never imagined that this idea was his own, believing that it was known to every student of vision. Previous to or during the year 1834, he had resolved to construct an instrument for uniting two dissimilar pictures, or of constructing a stereoscope ; but he delayed doing this till the year 1839, when he was requested to prepare an original communication for the Polytechnic Society, which had been recently established in Liverpool. He was thus induced to construct the instrument which he had projected, and he exhibited it to his friends, Mr. Richard Adie, optician, and Mr. George Hamilton, lecturer on chemistry in Liverpool, who bear testimony to its existence at that date. This simple stereoscope, without lenses or mirrors, consisted of a wooden box 18 inches long, 7 broad, and $4\frac{1}{2}$ deep, and at the bottom of it, or rather its farther end, was placed a slide containing two dissimilar pictures of a landscape as seen by each eye. Photography did not then exist, to enable Mr. Elliot to procure two views of the same scene, as seen by each eye, but he drew the transparency of a landscape with three distances. The *first* and most remote was the moon and the sky, and a stream of water from which the moon was reflected, the two moons being placed nearly at the distance of the two eyes, or $2\frac{1}{2}$ inches, and the two reflected moons at the same distance. The *second* distance was marked by an old cross about a hundred feet off ; and the *third* distance by the withered branch of a tree, thirty feet from the observer. In the right-hand picture, one arm of the cross just touched the disc of the moon, while, in the left-hand one, it projected over one-third of the disc. The branch of the tree

touched the outline of a distant hill in the one picture, but was "a full moon's-breadth" from it on the other. When these dissimilar pictures were united by the eyes, a landscape, certainly a very imperfect one, was seen in relief, composed of three distances.

Owing, no doubt, to the difficulty of procuring good binocular pictures, Mr. Elliot did not see that his contrivance would be very popular, and therefore carried it no farther. He had never heard of Mr. Wheatstone's stereoscope till he saw his paper on Vision reprinted in the *Philosophical Magazine* for March 1852, and having perused it, he was convinced not only that Mr. Wheatstone's theory of the instrument was incorrect, but that his claim to the discovery of the dissimilarity of the images in each eye had no foundation. He was, therefore, led to communicate to the same journal the fact of his having himself, thirteen years before, constructed and used a stereoscope, which was still in his possession. In making this claim, Mr. Elliot had no intention of depriving Mr. Wheatstone of the credit which was justly due to him; and as the claim has been publicly made, we have described the nature of it as a part of scientific history.

In Mr. Wheatstone's ingenious paper of 1838, the subject of binocular vision is treated at considerable length. He gives an account of the opinions of previous writers, referring repeatedly to the works of Aguilonius, Gassendi, and Baptista Porta, in the last of which the views of Galen are given and explained. In citing the passage which we have already quoted from Leonardo da Vinci, and inserting the figure which illustrates it, he maintains that Leonardo da Vinci was not aware "that the object (c in

Fig. 2) presented a different appearance to each eye." "*He failed,*" he adds, "*to observe this, and no subsequent writer, to my knowledge, has supplied the omission. The projection of two obviously dissimilar pictures on the two retinæ, when a single object is viewed, while the optic axes converge, must therefore be regarded as a new fact in the theory of vision.*" Now, although Leonardo da Vinci does not state in so many words that he was aware of the dissimilarity of the two pictures, the fact is obvious in his own figure, and he was not led by his subject to state the fact at all. But even if the fact had not stared him in the face he must have known it from the Optics of Euclid and the writings of Galen, with which he could not fail to have been well acquainted. That the dissimilarity of the two pictures is *not a new fact* we have already placed beyond a doubt. The fact is expressed in words, and delineated in drawings, by Aguilonius and Baptista Porta. It was obviously known to Dr. Smith, Mr. Harris, Dr. Porterfield, and Mr. Elliot, before it was known to Mr. Wheatstone, and we cannot understand how he failed to observe it in works which he has so often quoted, and in which he professes to have searched for it.

This remarkable property of binocular vision being thus clearly established by preceding writers, and admitted by himself, as the cause of the vision of solidity or distance, Mr. Wheatstone, as Mr. Elliot had done before him, thought of an instrument for uniting the two dissimilar pictures optically, so as to produce the same result that is obtained by the convergence of the optical axes. Mr. Elliot thought of doing this by the eyes alone; but Mr. Wheatstone adopted a much better method of doing it by reflexion.

He was thus led to construct an apparatus, to be afterwards described, consisting of two plane mirrors, placed at an angle of 90° , to which he gave the name of *stereoscope*, anticipating Mr. Elliot both in the construction and publication of his invention, but not in the general conception of a stereoscope.

After describing his apparatus, Mr. Wheatstone proceeds to consider (in a section entitled, "Binocular vision of objects of different magnitudes") "what effects will result from presenting similar images, differing only in magnitude, to analogous parts of the retina." "For this purpose," he says, "two squares or circles, *differing obviously* but not extravagantly in size, may be drawn on two separate pieces of paper, and placed in the stereoscope, so that the reflected image of each shall be equally distant from the eye by which it is regarded. *It will then be seen that notwithstanding this difference they coalesce and occasion a single resultant perception.*" The fact of coalescence being supposed to be perfect, the author next seeks to determine the difference between the length of two lines which the eye can force into coalescence, or "the limits within which the single appearance subsists." He, therefore, unites two images of equal magnitude, by making one of them visually less from distance, and he states that, "by this experiment, *the single appearance of two images of different size is demonstrated.*" Not satisfied with these erroneous assertions, he proceeds to give a sort of rule or law for ascertaining the relative size of the two unequal pictures which the eyes can force into coincidence. The inequality, he concludes, must not exceed the difference "between the projections of the same object when seen in the most oblique position of the eyes (*i.e.*,

both turned to the extreme right or the extreme left) ordinarily employed." Now, this rule, taken in the sense in which it is meant, is simply a *truism*. It merely states that the difference of the pictures which the eyes *can* make to coalesce is equal to the difference of the pictures which the eyes do make to coalesce in their most oblique position ; but though a *truism* it is not a *truth*, first, because no real coincidence ever can take place, and, secondly, because no apparent coincidence is effected when the difference of the picture is greater than what is above stated.

From these principles, which will afterwards be shewn to be erroneous, Mr. Wheatstone proceeds "to examine *why* two dissimilar pictures projected on the two retinae give rise to the perception of an object in relief." "I will not attempt," he says, "at present to give the complete solution of this question, which is far from being so easy as at first glance it may appear to be, and is, indeed, *one of great complexity*. I shall, in this case, merely consider the most obvious explanations which might be offered, and shew their insufficiency to explain the whole of the phenomena.

"*It may be supposed* that we see only one point of a field of view distinctly at the same instant, the one, namely, to which the optic axes are directed, while all other points are seen so indistinctly that the mind does not recognise them to be either single or double, and that the figure is appreciated by successively directing the point of convergence of the optic axes successively to a sufficient number of its points to enable us to judge accurately of its form.

"That there is a *degree of indistinctness* in those parts of the field of view to which the eyes are not immediately directed, and which increases with the distance from that

point, cannot be doubted ; and it is also true that the objects there obscurely seen are *frequently doubled*. In *ordinary* vision, it may be said, this indistinctness and duplicity are not attended to, because the eyes shifting continually from point to point, every part of the object is successively rendered distinct, and the perception of the object is not the consequence of a single glance, during which *a small part of it only is seen distinctly*, but is formed from a comparison of all the pictures successively seen, while the eyes were changing from one point of an object to another.

“ *All this is IN SOME DEGREE true, but were it entirely so no appearance of relief should present itself when the eyes remain intently fixed on one point of a binocular image in the stereoscope. But in performing the experiment carefully, it will be found, provided the picture do not extend far beyond the centres of distinct vision, that the image is still seen single, and in relief, when in this condition.*”¹

In this passage the author makes a distinction between *ordinary binocular vision*, and binocular vision through the stereoscope, whereas in reality there is none. The theory of both is exactly the same. The muscles of the two eyes unite the two dissimilar pictures, and exhibit the solid, in ordinary vision ; whereas in stereoscopic vision the images are united by reflexion or refraction, the eyes in both cases obtaining the vision of different distances by rapid and successive convergences of the optical axes. Mr. Wheatstone notices *the degree of indistinctness* in the parts of the picture to which the eyes are not immediately directed ; but he does not notice the “ *confusion and incongruity*” which

¹ *Phil. Trans.*, 1838, pp. 391, 392.

Aguilonius says ought to exist, in consequence of some parts of the resulting relieve being seen of one size by the left eye alone,—other parts of a different size by the right eye alone, and other parts by both eyes. This confusion, however, Aguilonius, as we have seen, found not to exist, and he ascribes it to the influence of a *common sense* overruling the operation of physical laws. Erroneous as this explanation is, it is still better than that of Mr. Wheatstone, which we shall now proceed to explain.

In order to disprove the theory referred to in the preceding extract, Mr. Wheatstone describes two experiments, which he says *are equally decisive against it*, the first of them only being subject to rigorous examination. With this view he draws “two lines about two inches long, and inclined towards each other, on a sheet of paper, and having caused them to coincide by converging the optic axes to a point nearer than the paper, he looks intently on the upper end of the resultant line without allowing the eyes to wander from it for a moment. *The entire line will appear single*, and in its proper relief, &c. . . . The eyes,” he continues, “sometimes become fatigued, which causes the line to become double at those parts to which the optic axes are not fixed, *but in such case all appearance of relief vanishes*. The same experiment may be tried with small complex figures, but the pictures should not extend too far beyond the centre of the retinae.”

Now these experiments, if rightly made and interpreted, are not *decisive against* the theory. It is not true that the entire line appears single when the axes are converged upon the upper end of the resultant line, and it is not true that the disappearance of the relief when it does disappear arises

from the eye being fatigued. In the combination of more complex figures, such as two similar rectilineal figures contained by lines of unequal length, neither the inequalities nor the entire figure will appear single when the axes are converged upon any one point of it.

In the different passages which we have quoted from Mr. Wheatstone's paper, and in the other parts of it which relate to binocular vision, he is obviously halting between truth and error, between theories which he partly believes, and ill-observed facts which he cannot reconcile with them. According to him, certain truths "may be supposed" to be true, and other truths may be "in some degree 'true,'" but "not entirely so;" and thus, as he confesses, the problem of binocular and stereoscopic vision "is indeed one of great complexity," of which "he will not attempt at present to give the complete solution." If he had placed a proper reliance on the law of visible direction which he acknowledges I have established, and "with which," he says, "the laws of visible direction for binocular vision ought to contain nothing inconsistent," he would have seen the impossibility of the two eyes uniting two lines of unequal length; and had he believed in the law of distinct vision he would have seen the impossibility of the two eyes obtaining single vision of any more than one point of an object at a time. These laws of vision are as rigorously true as any other physical laws,—as completely demonstrated as the law of gravity in Astronomy, or the law of the Sines in Optics; and the moment we allow them to be tampered with to obtain an explanation of physical puzzles, we convert science into legerdemain, and philosophers into conjurors.

Such was the state of our stereoscopic knowledge in

1838, after the publication of Mr. Wheatstone's interesting and important paper. Previous to this I communicated to the British Association at Newcastle, in August 1838, a paper, in which I established the law of visible direction already mentioned, which, though it had been maintained by preceding writers, had been proved by the illustrious D'Alembert to be incompatible with observation, and the admitted anatomy of the human eye. At the same meeting Mr. Wheatstone exhibited his stereoscopic apparatus, which gave rise to an animated discussion on the theory of the instrument. Dr. Whewell maintained that the retina, in uniting, or causing to coalesce into a single resultant impression two lines of different lengths, had the power either of contracting the longest, or lengthening the shortest, or what might have been suggested in order to give the retina only half the trouble, that it contracted the long line as much as it expanded the short one, and thus caused them to combine with a less exertion of muscular power! In opposition to these views, I maintained that the retina, a soft pulpy membrane which the smallest force tears in pieces, had no such power,—that a hypothesis so gratuitous was not required, and that the law of visible direction afforded the most perfect explanation of all the stereoscopic phenomena.

In consequence of this discussion, I was led to repeat my experiments, and to inquire whether or not the eyes in stereoscopic vision *did actually* unite the two lines of different lengths, or of different apparent magnitudes. I found that they did not, and that no such union was required to convert by the stereoscope two plane pictures into the apparent whole from which they were taken as seen by each

eye. These views were made public in the lectures on the *Philosophy of the Senses*, which I occasionally delivered in the College of St. Salvator and St. Leonard, St. Andrews, and the different stereoscopes which I had invented were also exhibited and explained.

In examining Dr. Berkeley's celebrated Theory of Vision, I saw the vast importance of establishing the law of visible direction, and of proving by the aid of binocular phenomena, and in opposition to the opinion of the most distinguished metaphysicians, that we actually see a third dimension in space, I therefore submitted to the Royal Society of Edinburgh, in January 1843, a paper *On the law of visible position in single and binocular vision, and on the representation of solid figures by the union of dissimilar plane pictures on the retina*. More than twelve years have now elapsed since this paper was read, and neither Mr. Wheatstone nor Dr. Whewell have made any attempt to defend the views which it refutes.

In continuing my researches, I communicated to the Royal Society of Edinburgh, in April 1844, a paper *On the knowledge of distance as given by binocular vision*, in which I described several interesting phenomena produced by the union of *similar* pictures, such as those which form the patterns of carpets and paper-hangings. In carrying on these inquiries I found the reflecting stereoscope of little service, and ill fitted, not only for popular use, but for the application of the instrument to various useful purposes. I was thus led to the construction of several new stereoscopes, but particularly to the *Lenticular Stereoscope*, now in universal use. They were constructed in St. Andrews and Dundee, of various materials, such as wood, tinplate, brass,

and of all sizes, from that now generally adopted, to a microscopic variety which could be carried in the pocket. New geometrical drawings were executed for them, and binocular pictures taken by the sun were lithographed by Mr. Schenck of Edinburgh. Stereoscopes of the lenticular form were made by Mr. Loudon, optician, in Dundee, and sent to several of the nobility in London, and in other places, and an account of these stereoscopes, and of a binocular camera for taking portraits, and copying statues, was communicated to the Royal Scottish Society of Arts, and published in their Transactions.

It had never been proposed to apply the reflecting stereoscope to portraiture or sculpture, or, indeed, to any useful purpose; but it was very obvious, after the discovery of the Daguerreotype and Talbotype, that binocular drawings could be taken with such accuracy as to exhibit in the stereoscope excellent representations in relief, both of living persons, buildings, landscape scenery, and every variety of sculpture. In order to shew its application to the most interesting of these purposes, Dr. Adamson of St. Andrews, at my request, executed two binocular portraits of himself, which were generally circulated and greatly admired. This successful application of the principle to portraiture was communicated to the public, and recommended as an art of great domestic interest.

After endeavouring in vain to induce opticians, both in London and Birmingham, (where the instrument was exhibited in 1849 to the British Association,) to construct the lenticular stereoscope, and photographers to execute binocular pictures for it, I took with me to Paris, in 1850, a very fine instrument, made by Mr. Loudon in Dundee, with the binocular drawings and portraits already mentioned. I shewed

the instrument to the Abbé Moigno, the distinguished author of *L'Optique Moderne*, to M. Soleil and his son-in-law, M. Duboscq, the eminent Parisian opticians, and to some members of the Institute of France. These gentlemen saw at once the value of the instrument, not merely as one of amusement, but as an important auxiliary in the arts of portraiture and sculpture. M. Duboscq immediately began to make the lenticular stereoscope for sale, and executed a series of the most beautiful binocular Daguerreotypes of living individuals, statues, bouquets of flowers, and objects of natural history, which thousands of individuals flocked to examine and admire. In an interesting article in *La Presse*,¹ the Abbé Moigno gave the following account of the introduction of the instrument into Paris :—

“ In his last visit to Paris, Sir David Brewster intrusted the models of his stereoscope to M. Jules Duboscq, son-in-law and successor of M. Soleil, and whose intelligence, activity, and affability will extend the reputation of the distinguished artists of the Rue de l’Odeon, 35. M. Jules Duboscq has set himself to work with indefatigable ardour. Without requiring to have recourse to the binocular camera, he has, with the ordinary Daguerreotype apparatus, procured a great number of dissimilar pictures of statues, bas-reliefs, and portraits of celebrated individuals, &c. His stereoscopes are constructed with more elegance, and even with more perfection, than the original English (Scotch) instruments, and while he is shewing their wonderful effects to natural philosophers and amateurs who have flocked to him in crowds, there is a spontaneous and unanimous cry of admiration.”

¹ December 28, 1850.

While the lenticular stereoscope was thus exciting much interest in Paris, not a single instrument had been made in London, and it was not till a year after its introduction into France that it was exhibited in England. In the fine collection of philosophical instruments which M. Duboscq contributed to the Great Exhibition of 1851, and for which he was honoured with a Council medal, he placed a lenticular stereoscope, with a beautiful set of binocular Daguerreotypes. This instrument attracted the particular attention of the Queen, and before the closing of the Crystal Palace, M. Duboscq executed a beautiful stereoscope, which I presented to Her Majesty in his name. In consequence of this public exhibition of the instrument, M. Duboscq received several orders from England, and a large number of stereoscopes were thus introduced into this country. The demand, however, became so great, that opticians of all kinds devoted themselves to the manufacture of the instrument, and photographers, both in Daguerreotype and Talbotype, found it a most lucrative branch of their profession, to take binocular portraits of views to be thrown into relief by the stereoscope. Its application to sculpture, which I had pointed out, was first made in France, and an artist in Paris actually copied a statue from the *relievo* produced by the stereoscope.

Three years after I had published a description of the lenticular stereoscope, and after it had been in general use in France and England, and the reflecting stereoscope forgotten,¹ Mr. Wheatstone printed, in the *Philosophical Transactions* for 1852, a paper on Vision, in which he says

¹ "Le fait est," says the Abbé Moigno, "que le stéréoscope par réflexion était presque complètement oublié, lorsque Sir David Brewster construisit son stéréoscope par réfraction que nous allons décrire."—*Cosmos*, vol. i. p. 4, 1852.

that he had previously used "an apparatus in which *prisms* were employed to deflect the rays of light proceeding from the pictures, so as to make them appear to occupy the same place;" and he adds, "I have called it the *refracting* stereoscope."¹ Now, whatever Mr. Wheatstone may have done with prisms, and at whatever time he may have done it, I was the first person who published a description of stereoscopes both with *refracting* and reflecting prisms; and during the three years that elapsed after he had read my paper, he made no claim to the suggestion of prisms till after the great success of the lenticular stereoscope. The reason why he then made the claim, and the only reason why we do not make him a present of the suggestion, will appear from the following history:—

In the paper above referred to, Mr. Wheatstone says,—
"I recommend, as a convenient arrangement of the *refracting* stereoscope for viewing Daguerreotypes of small dimensions, the instrument represented, (Fig. 4,) shortened in its length from 8 inches to 5, and lenses 5 inches focal distance, placed before and close to the prisms."² Although this refracting apparatus, which is simply a *deterioration* of the lenticular stereoscope, is recommended by Mr. Wheatstone, nobody either makes it or uses it. The semi-lenses or quarter-lenses of the lenticular stereoscope *include a virtual and absolutely perfect prism*, and, what is of far more consequence, each lens is a variable lenticular prism, so that, when the eye-tubes are placed at different distances, the lenses have different powers of displacing the pictures. They can thus unite pictures placed at different distances, which cannot be done by any combination of whole lenses and prisms.

¹ *Phil. Trans.*, 1832, p. 6.

² *Ibid.*, pp. 2, 10.

In the autumn of 1854, after all the facts about the stereoscope were before the public, and Mr. Wheatstone in full possession of all the merit of having anticipated Mr. Elliot in the publication of his stereoscopic apparatus, and of his explanation of the theory of stereoscopic relief, such as it was, he thought it proper to revive the controversy by transmitting to the Abbé Moigno, for publication in *Cosmos*, an extract of a letter of mine dated 27th September 1838. This extract was published in the *Cosmos* of the 15th August 1854,¹ with the following illogical commentary by the editor.

“ Nous avons eu tort mille fois d'accorder à notre illustre ami, Sir David Brewster, l'invention du stéréoscope par réfraction. M. Wheatstone, en effet, a mis entre nos mains une lettre datée, le croirait on, du 27 Septembre 1838, dans lequel nous avons lû ces mots écrits par l'illustre savant Ecossais : ‘ I have also stated that you promised to order for me your stereoscope, both with reflectors and PRISMS. J'ai aussi dit (à Lord Rosse²) que vous aviez promis de commander pour moi votre stéréoscope, celui avec réflecteurs et celui avec prismes.’ Le stéréoscope par réfraction est donc, aussi bien que le stéréoscope par réflexion, le stéréoscope de M. Wheatstone, qui l'avait inventé en 1838, et le faisait construire à cette époque pour Sir David Brewster lui-même. Ce que Sir David Brewster a imaginée, et c'est une idée très ingénieuse, dont M. Wheatstone ne lui disputât jamais la gloire, c'est de former les deux prismes du stéréoscope par réfraction avec les deux moitiés d'une même lentille.”

That the reader may form a correct idea of the conduct of Mr. Wheatstone in making this claim indirectly, and in

¹ Vol. v. livre viii. p. 241.

² Mr. Andrew Ross, the celebrated optician !

a foreign journal, whose editor he has willingly misled, I must remind him that I first saw the reflecting stereoscope at the meeting of the British Association at Newcastle, in the middle of *August* 1838. It is proved by my letter that he and I then conversed on the subject of *prisms*, which at that time he had never thought of. I suggested prisms for displacing the pictures, and Mr. Wheatstone's natural reply was, that they must be *achromatic prisms*. This fact, if denied, may be proved by various circumstances. His paper of 1838 contains no reference to prisms. If he had suggested the use of prisms in August 1838, he would have inserted his suggestion in that paper, which was then unpublished; and if he had *only once* tried a prism stereoscope, he never would have used another. On my return to Scotland, I ordered from Mr. Andrew Ross one of the reflecting stereoscopes, and one made with achromatic prisms; but my words do not imply that Mr. Wheatstone was the first person who suggested prisms, and still less that he ever made or used a stereoscope with prisms. But however this may be, it is a most extraordinary statement, which he allows the Abbé Moigno to make, and which, though made a year and a half ago, he has not enabled the Abbé to correct, *that a stereoscope with prisms was made for me* (or for any other person) *by Mr. Ross*. I never saw such an instrument, or heard of its being constructed: I supposed that after our conversation Mr. Wheatstone might have tried achromatic prisms, and in 1848, when I described my single prism stereoscope, I stated what I now find is not correct, that *I believed* Mr. Wheatstone had used *two* achromatic prisms. The following letter from Mr. Andrew Ross will prove the main fact that he never constructed

for me, or for Mr. Wheatstone, any refracting stereoscope :—

“2, FEATHERSTONE BUILDINGS,
28th September 1854.

“DEAR SIR,—In reply to yours of the 11th instant, I beg to state that I never supplied you with a stereoscope in which prisms were employed in place of plane mirrors. I have a perfect recollection of being called upon either by yourself or Professor Wheatstone, some fourteen years since, to make achromatized prisms for the above instrument. I also recollect that I did not proceed to manufacture them in consequence of the great bulk of an achromatized prism, with reference to their power of deviating a ray of light, and at that period glass sufficiently free from striæ could not readily be obtained, and was consequently very high-priced.—I remain, &c. &c.

“ANDREW ROSS.

“To Sir David Brewster.”

Upon the receipt of this letter I transmitted a copy of it to the Abbé Moigno, to shew him how he had been misled into the statement, “that Mr. Wheatstone had caused a stereoscope with prisms to be constructed for me;” but neither he nor Mr. Wheatstone have felt it their duty to withdraw that erroneous statement.

In reference to the comments of the Abbé Moigno, it is necessary to state, that when he wrote them he had in his possession my printed description of the single prism, and other stereoscopes,¹ in which I mention my belief, now

¹ The Abbé gave an abstract of this paper in the French journal *La Presse*, December 28, 1850.

proved to be erroneous, that Mr. Wheatstone had used achromatic prisma, so that he had, on my express authority, the information which surprised him in my letter. The Abbé also must bear the responsibility of a glaring misinterpretation of my letter of 1838. In that letter I say that Mr. Wheatstone promised *to order certain things from Mr. Ross*, and the Abbé declares, contrary to the express terms of the letter, as well as to fact, *that these things were actually constructed for me*. The letter, on the contrary, does not even state that Mr. Wheatstone complied with my request, and it does not even appear from it that the reflecting stereoscope was made for me by Mr. Ross.

Such is a brief history of the lenticular stereoscope, of its introduction into Paris and London, and of its application to portraiture and sculpture. It is now in general use over the whole world, and it has been estimated that upwards of half a million of these instruments have been sold. A Stereoscope Company has been established in London² for the manufacture and sale of the lenticular stereoscope, and for the production of binocular pictures for educational and other purposes. Photographers are now employed in every part of the globe in taking binocular pictures for the instrument,—among the ruins of Pompeii and Herculaneum—on the glaciers and in the valleys of Switzerland—among the public monuments in the Old and the New World—amid the shipping of our commercial harbours—in the museums of ancient and modern life—in the sacred precincts

¹ No. 54, Cheapside, and 313, Oxford Street. The prize of twenty guineas which they offered for the best short popular treatise on the Stereoscope, has been adjudged to Mr. Lonie, Teacher of Mathematics in the Madras Institution, St. Andrews. The second prize was given to the Rev. R. Graham, Abernethy, Perthshire.

of the domestic circle—and among those scenes of the picturesque and the sublime which are so affectionately associated with the recollection of our early days, and amid which, even at the close of life, we renew, with loftier sentiments and nobler aspirations, the youth of our being, which, in the worlds of the future, is to be the commencement of a longer and a happier existence.

CHAPTER II.

ON MONOCULAR VISION, OR VISION WITH ONE EYE.

IN order to understand the theory and construction of the stereoscope we must be acquainted with the general structure of the eye, with the mode in which the images of visible objects are formed within it, and with the laws of vision by means of which we see those objects in the position which they occupy, that is, in the direction and at the distance at which they exist.

Every visible object radiates, or throws out in all directions, particles or rays of light, by means of which we see them either directly by the images formed in the eye, or indirectly by looking at images of them formed by their passing through a small hole, or through a lens placed in a dark room or *camera*, at the end of which is a piece of paper or ground glass to receive the image.

In order to understand this let H be a very small pin-hole in a shutter or camera, MN , and let EYB be any object of different colours, the upper part, E , being *red*, the middle, Y , *yellow*, and the lower part, B , *blue*. If a sheet of white paper, br , is placed behind the hole H , at the same distance as the object EYB is before it, an image, br , will be formed of the same ray and the same colours as the object EYB . As the particles or rays of light move in

straight lines, a *red* ray from the middle part of *R* will pass through the hole *H* and illuminate the point *r* with *red* light. In like manner, rays from the middle points of

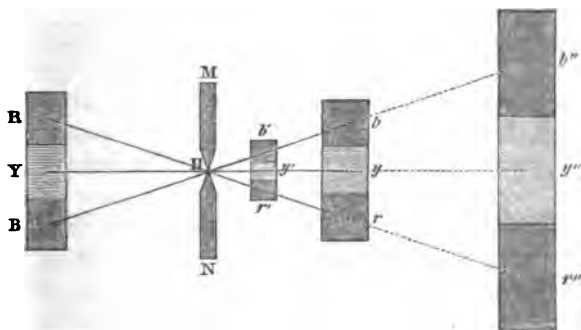


FIG. 4.

Y and *B* will pass through *H* and illuminate with *yellow* and *blue* light the points *y* and *b*. Every other point of the coloured spaces, *R*, *Y*, and *B*, will, in the same manner, paint itself, as it were, on the paper, and produce a coloured image, *b y r*, exactly the same in form and colour as the object *R Y B*. If the hole *H* is sufficiently small no ray from any one point of the object will interfere with or mix with any other ray that falls upon the paper. If the paper is held at *half* the distance, at *b'y'r'* for example, a coloured image, *b'y'r'*, of half the size, will be formed, and if we hold it at *twice* the distance, at *b''y''r''* for example, a coloured image, *b''y''r''*, of *twice* the size, will be painted on the paper.

As the hole *H* is supposed to be so small as to receive only one ray from every point of the object, the images of the object, viz., *b r*, *b'r'*, *b''r''*, will be very faint. By widening

the hole H , so as to admit more rays from each luminous point of EB , the images would become brighter, but they would become at the same time indistinct, as the rays from one point of the object would mix with those from adjacent points, and at the boundaries of the colours R , Y , and B , the one colour would obliterate the other. In order, therefore, to obtain sufficiently bright images of visible objects we must use *lenses*, which have the property of forming distinct images behind them, at a point called their focus. If we widen the hole H , and place in it a lens whose focus is at y , for an object at the same distance, HY , it will form a bright and distinct image, br , of the same size as the object EB . If we remove the lens, and place another in H , whose focus is at y' , for a distance HY , an image, $b'r'$, half of the size of EB , will be formed at that point; and if we substitute for this lens another, whose focus is at y'' , a distinct image, $b''r''$, twice the size of the object, will be formed, the size of the image being always to that of the object as their respective distances from the hole or lens at H .

With the aid of these results, which any person may confirm by making the experiments, we shall easily understand how we see external objects by means of the images formed in the eye. The human eye, a section and a front view of which is shewn in Fig. 5, A , is almost a sphere. Its outer membrane, $ABCDE$, or MNO , Fig. 5, B , consists of a tough substance, and is called the *sclerotic coat*, which forms the *white of the eye*, A , seen in the front view. The front part of the eyeball, oxd , which resembles a small watch-glass, is perfectly transparent, and is called the *cornea*. Behind it is the *iris*, *cabe*, or c in the front view, which is

a circular disc, with a hole, ab , in its centre, called the *pupil*, or *black of the eye*. It is, as it were, the *window* of the eye, through which all the light from visible objects must pass.

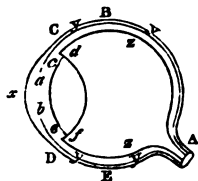


FIG. 5, A.



The *iris* has different colours in different persons, *black*, *blue*, or *grey*; and the pupil, ab , or H , has the power of contracting or enlarging its size according as the light which enters it is more or less bright. In sunlight it is very small, and in twilight its size is considerable. Behind the iris, and close to it, is a doubly convex lens, df , or LL in Fig. 5, B, called

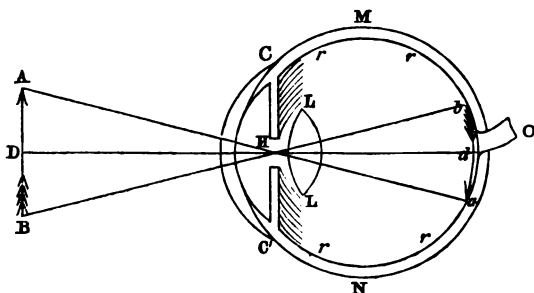


FIG. 5, B.

the *crystalline lens*. It is more convex or round on the inner side, and it is suspended by the *ciliary processes* at Lc , Lc' , by which it is supposed to be moved towards and from H , in order to accommodate the eye to different dis-

tances, or obtain distinct vision at these distances. At the back of the eye is a thin pulpy transparent membrane, *rr o rr*, or *vvv*, called the *retina*, which, like the ground glass of a camera obscura, receives the images of visible objects. This membrane is an expansion of the optic nerve *o*, or *A* in Fig. 5, *A*, which passes to the brain, and, by a process of which we are ignorant, gives us vision of the objects whose images are formed on its expanded surface. The globular form of the eye is maintained by two fluids which fill it,—the *aqueous humour*, which lies between the crystalline lens and the cornea, and the *vitreous humour*, *zz*, which fills the back of the eye.

But though we are ignorant of the manner in which the mind takes cognizance through the brain of the images on the retina, and may probably never know it, we can determine experimentally the laws by which we obtain, through their images on the retina, a knowledge of the direction, the position, and the form of external objects.

If the eye *MN* consisted only of a hollow ball with a small aperture *H*, an inverted image, *ab*, of any external object *AB* would be formed on the retina *ror*, exactly as in Fig. 4. A ray of light from *A* passing through *H* would strike the retina at *a*, and one from *B* would strike the retina at *b*. If the hole *H* is very small the inverted image *ab* would be very distinct, but very obscure. If the hole were the size of the pupil the image would be sufficiently luminous, but very indistinct. To remedy this the crystalline lens is placed behind the pupil, and gives distinctness to the image *ab* formed in its focus. The image, however, still remains inverted, a ray from the *upper* part *A* of the object necessarily falling on the *lower* part *a* of the retina,

and a ray from the *lower* part B of the object upon the upper part *b* of the retina. Now, it has been proved by accurate experiments that in whatever direction a ray $\Delta H a$ falls upon the retina, it gives us the vision of the point Δ from which it proceeds, or causes us to see that point, in a direction perpendicular to the retina at *a*, the point on which it falls. It has also been proved that the human eye is nearly spherical, and that a line drawn perpendicular to the retina from any point *a* of the image *ab* will very nearly pass through the corresponding point Δ of the object ΔB ,¹ so that the point Δ is, in virtue of this law, which is called the *Law of visible direction*, seen in nearly its true direction.

When we look at any object, ΔB , for example, we see only one point of it distinctly. In Fig. 5 the point D only is seen distinctly, and every point from D to A, and from D to B, less distinctly. The point of distinct vision on the retina is at *d*, corresponding with the point D of the object which is seen distinctly. This point *d* is the centre of the retina at the extremity of the line $\Delta H a$, called the optical axis of the eye, passing through the centre of the lens *Lh*, and the centre of the pupil. The point of distinct vision *d* corresponds with a small hole in the retina called the *Foramen centrale*, or *central hole*, from its being in the centre of the membrane. When we wish to see the points A and B, or any other point of the object, we turn the eye upon them, so that their image may fall upon the central point *d*. This is done so easily and quickly that every point of an object is seen distinctly in an instant, and we obtain the most perfect knowledge of its form, colour, and direction.

¹ *Edinburgh Transactions*, vol. xv. p. 349, 1843; or *Philosophical Magazine*, vol. xxv. pp. 356, 439, May and June 1844.

The law of distinct vision may be thus expressed. Vision is most distinct when it is performed by the central point of the retina, and the distinctness decreases with the distance from the central point. It is a curious fact, however, that the most *distinct point* *d* is the *least sensitive to light*, and that the sensitiveness increases with the distance from that point. This is proved by the remarkable fact, that when an astronomer cannot see a very minute star by looking at it directly along the optical axis dD , he can see it *by looking away from it*, and bringing its image upon a more sensitive part of the retina.

But though we see with one eye the direction in which any object or point of an object is situated, we do not see its position, or the distance from the eye at which it is placed. If a small luminous point or flame is put into a dark room by another person, we cannot with one eye form anything like a correct estimate of its distance. Even in good light we cannot with one eye snuff a candle, or pour wine into a small glass at arm's length. In monocular vision, we learn from experience to estimate all distances, but particularly great ones, by various means, which are called the *criteria of distance*; but it is only with both eyes that we can estimate with anything like accuracy the distance of objects not far from us.

The *criteria of distance*, by which we are enabled with one eye to form an approximate estimate of the distance of objects are five in number.

1. The interposition of numerous objects between the eye and the object whose distance we are appreciating. A distance at sea appears much shorter than the same distance on land, marked with houses, trees, and other objects; and

for the same reason, the sun and moon appear more distant when rising or setting on the horizon of a flat country, than when in the zenith, or at great altitudes.

2. The variation in the apparent magnitude of known objects, such as man, animals, trees, doors and windows of houses. If one of two men, placed at different distances from us, appears only half the size of the other, we cannot be far wrong in believing that the smallest in appearance is at twice the distance of the other. It is possible that the one may be a dwarf, and the other of gigantic stature, in which case our judgment would be erroneous, but even in this case other criteria might enable us to correct it.

3. The degree of vivacity in the colours and tints of objects.

4. The degree of distinctness in the outline and minute parts of objects.

5. To these criteria we may add the sensation of muscular action, or rather effort, by which we close the pupil in accommodating the eye to near distances, and produce the accommodation.

With all these means of estimating distances, it is only by binocular vision, in which we converge the optical axes upon the object, that we have the power of *seeing distance* within a limited range.

But this is the only point in which Monocular is *inferior* to Binocular vision. In the following respects it is *superior* to it.

1. When we look at oil paintings, the varnish on their surface reflects to each eye the light which falls upon it from certain parts of the room. By closing one eye we shut out the quantity of reflected light which enters it.

Pictures should always be viewed by the eye farthest from windows or lights in the apartment, as light diminishes the sensibility of the eye to the red rays.

2. When we view a picture with both eyes, we discover, from the convergency of the optic axes, that the picture is on a plane surface, every part of which is nearly equidistant from us. But when we shut one eye, we do not make this discovery; and therefore the effect with which the artist gives relief to the painting exercises its whole effect in deceiving us, and hence, in monocular vision, the *relievo* of the painting is much more complete.

This influence over our judgment is beautifully shewn in viewing, with one eye, photographs either of persons, or landscapes, or solid objects. After a little practice, the illusion is very perfect, and is aided by the correct geometrical perspective and *chiaroscuro* of the Daguerreotype or Talbotype. To this effect we may give the name of *Monocular Relief*, which, as we shall see, is necessarily inferior to *Binocular Relief*, when produced by the stereoscope.

3. As it very frequently happens that one eye has not exactly the same focal length as the other, and that, when it has, the vision by one eye is less perfect than that by the other, the picture formed by uniting a perfect with a less perfect picture, or with one of a different size, must be more imperfect than the single picture formed by one eye.

CHAPTER III.

ON BINOCULAR VISION, OR VISION WITH TWO EYES.

WE have already seen, in the history of the stereoscope, that in the binocular vision of objects, each eye sees a different picture of the same object. In order to prove this, we require only to look attentively at our own hand held up before us, and observe how some parts of it disappear upon closing each eye. This experiment proves, at the same time, in opposition to the opinion of Baptista Porta, Tacquet, and others, that we always see two pictures of the same object combined in one. In confirmation of this fact, we have only to push aside one eye, and observe the image which belongs to it separate from the other, and again unite with it when the pressure is removed.

It might have been supposed that an object seen by both eyes would be seen twice as brightly as with one, on the same principle as the light of two candles combined is twice as bright as the light of one. That this is not the case has been long known, and Dr. Jurin has proved by experiments, which we have carefully repeated and found correct, that the brightness of objects seen with two eyes is only $\frac{1}{2}$ th part greater than when they are seen with one eye.¹ The cause

¹ Smith's *Opticks*, vol. ii., Remarks, p. 107. Harris makes the difference $\frac{1}{5}$ th or $\frac{1}{11}$ th; *Optics*, p. 117.

of this is well known. When both eyes are used, the pupils of each contract so as to admit the proper quantity of light ; but the moment we shut the right eye, the pupil of the left dilates to nearly twice its size, to compensate for the loss of light arising from the shutting of the other.¹

This beautiful provision to supply the proper quantity of light when we can use only one eye, answers a still more important purpose, which has escaped the notice of optical writers. In binocular vision, as we have just seen, certain parts of objects are seen with both eyes, and certain parts only with one ; so that, if the parts seen with both eyes were twice as bright, or even much brighter than the parts seen with one, the object would appear spotted, from the different brightness of its parts. In Fig. 6, for example, (see p. 14,)

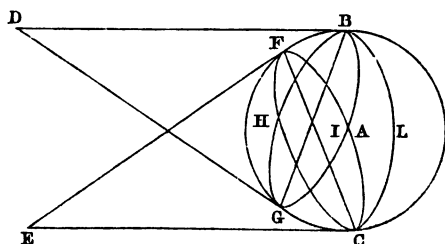


FIG. 6.

the areas BFI and CGI, the former of which is seen only by the left eye, D, and the latter only by the right eye, E, and the corresponding areas on the other side of the sphere, would be only half as bright as the portion FIGH, seen with both eyes, and the sphere would have a singular appearance.

It has long been, and still is, a vexed question among

¹ This variation of the pupil is mentioned by Bacon.

philosophers, how we see objects single with two eyes. Baptista Porta, Tacquet, and others, got over the difficulty by denying the fact, and maintaining that we use only one eye, while other philosophers of distinguished eminence have adopted explanations still more groundless. The law of visible direction supplies us with the true explanation.

Let us first suppose that we look with both eyes, R and L, Fig. 7, upon a luminous point, D, which we see single,

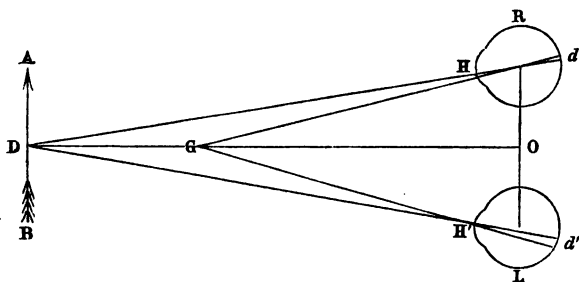


FIG. 7.

though there is a picture of it on the retina of each eye. In looking at the point D we turn or converge the optical axes dHD , $d'H'D$, of each eye to the point D, an image of which is formed at d in the right eye R, and at d' in the left eye L. In virtue of the law of visible direction the point D is seen in the direction dD with the eye R, and in the direction $d'D$ with the eye L, these lines being perpendicular to the retina at the points d , d' . The one image of the point D is therefore seen lying upon the other, and consequently seen single. Considering D, then, as a single point of a visible object AB, the two eyes will see the points A and B single by the same process of turning or converg-

ing upon them their optical axes, and so quickly does the point of convergence pass backward and forward over the whole object, that it appears single, though in reality only one point of it can be seen single at the same instant. The whole picture of the line *AB*, as seen with one eye, *seems* to coincide with the whole picture of it as seen with the *other*, and to appear single. The same is true of a surface or area, and also of a solid body or a landscape. Only one point of each is seen single; but we do not observe that other points are double or indistinct, because the images of them are upon parts of the retina which do not give distinct vision, owing to their distance from the *foramen* or point which gives distinct vision. Hence we see the reason why distinct vision is obtained only on one point of the retina. Were it otherwise we should see every other point double when we look fixedly upon one part of an object. If in place of *two* eyes we had a *hundred*, capable of converging their optical axes to one point, we should, in virtue of the law of visible direction, see only *one* object.

The most important advantage which we derive from the use of two eyes is to enable us to *see distance*, or a third dimension in space. That we have this power has been denied by Dr. Berkeley, and many distinguished philosophers, who maintain that our perception of distance is acquired by experience, by means of the criteria already mentioned. This is undoubtedly true for great distances, but we shall presently see, from the effects of the stereoscope, that the successive convergency of the optic axes upon two points of an object at different distances, exhibits to us the difference of distance when we have no other

possible means of perceiving it. If, for example, we suppose G, D , Fig. 7, to be separate points, or parts of an object, whose distances are GO, DO , then if we converge the optical axes $HG, H'G$ upon G , and next turn them upon D , the points will appear to be situated at G and D at the distance GD from each other, and at the distances OG, OD from the observer, although there is nothing whatever in the appearance of the points, or in the lights and shades of the object, to indicate distance. That this vision of distance is not the result of experience is obvious from the fact that distance is seen as perfectly by children as by adults; and it has been proved by naturalists that animals newly born appreciate distances with the greatest correctness. We shall afterwards see that so infallible is our vision of near distances, that a body whose real distance we can ascertain by placing both our hands upon it, will appear at the greater or less distance at which it is placed by the convergency of the optical axes.

We are now prepared to understand generally, how, in binocular vision, we see the difference between a picture and a statue, and between a real landscape and its representation. When we look at a picture of which every part is nearly at the same distance from the eyes, the point of convergence of the optical axes is nearly at the same distance from the eyes; but when we look at its original, whether it be a living man, a statue, or a landscape, the optical axes are converged in rapid succession upon the nose, the eyes, and the ears, or upon objects in the foreground, the middle and the remote distances in the landscape, and the relative distances of all these points from the eye are instantly perceived. The *binocular relief* thus

seen is greatly superior to the *monocular relief* already described.

Since objects are seen in relief by the apparent union of two dissimilar plane pictures of them formed in each eye, it was a supposition hardly to be overlooked, that if we could delineate two plane pictures of a solid object, as seen dissimilarly with each eye, and unite their images by the convergency of the optical axes, we should see the solid of which they were the representation. The experiment was accordingly made by more than one person, and was found to succeed ; but as few have the power, or rather the art, of thus converging their optical axes, it became necessary to contrive an instrument for doing this.

The first contrivances for this purpose were, as we have already stated, made by Mr. Elliot and Mr. Wheatstone. A description of these, and of others better fitted for the purpose, will be found in the following chapter.

CHAPTER IV.

DESCRIPTION OF THE OCULAR, THE REFLECTING, AND THE
LENTICULAR STEREOSCOPIES.

ALTHOUGH it is by the combination of two plane pictures of an object, as seen by each eye, that we see the object in relief, yet the relief is not obtained from the mere combination or superposition of the two dissimilar pictures. The superposition is effected by turning each eye upon the object, but the relief is given by the play of the optic axes in uniting, in rapid succession, similar points of the two pictures, and placing them, for the moment, at the distance from the observer of the point to which the axes converge. If the eyes were to unite the two images into one, and to retain their power of distinct vision, while they lost the power of changing the position of their optic axes, no relief would be produced.

This is equally true when we unite two dissimilar photographic pictures by fixing the optic axes on a point nearer to or farther from the eye. Though the pictures apparently coalesce, yet the relief is given by the subsequent play of the optic axes varying their angles, and converging themselves successively upon, and uniting, the similar points in each picture that correspond to different distances from the observer.

As very few persons have the power of thus uniting, by the eyes alone, the two dissimilar pictures of the object, the stereoscope has been contrived to enable them to combine the two pictures, but it is not the stereoscope, as has been imagined, that gives the relief. The instrument is merely a substitute for the muscular power which brings the two pictures together. The relief is produced, as formerly, solely by the subsequent play of the optic axes. If the relief were the effect of the apparent union of the pictures, we should see it by looking with one eye at the combined binocular pictures—an experiment which could be made by optical means; but we should look for it in vain. The combined pictures would be as flat as the combination of two similar pictures. These experiments require to be made with a thorough knowledge of the subject, for when the eyes are converged on one point of the combined picture, this point has the relief, or distance from the eye, corresponding to the angle of the optic axes, and therefore the adjacent points are, as it were, brought into a sort of indistinct relief along with it; but the optical reader will see at once that the true binocular relief cannot be given to any other parts of the picture, till the axes of the eyes are converged upon them. These views will be more readily comprehended when we have explained, in a subsequent chapter, the theory of stereoscopic vision.

The Ocular Stereoscope.

We have already stated that objects are seen in perfect relief when we unite two dissimilar photographic pictures of them, either by converging the optic axes upon a point so far in front of the pictures or so far beyond them, that two

of the four images are combined. In both these cases each picture is seen double, and when the two innermost of the four, thus produced, unite, the original object is seen in relief. The simplest of these methods is to converge the optical axes to a point nearer to us than the pictures, and this may be best done by holding up a finger between the eyes and the pictures, and placing it at such a distance that, when we see it single, the two innermost of the four pictures are united. If the finger is held up near the dissimilar pictures, they will be slightly doubled, the two images of each overlapping one other; but by bringing the finger nearer the eye, and seeing it singly and distinctly, the overlapping images will separate more and more till they unite. We have, therefore, made our eyes a stereoscope, and we may, with great propriety, call it the *Ocular Stereoscope*. If we wish to magnify the picture in relief, we have only to use convex spectacles, which will produce the requisite magnifying power; or what is still better, to magnify the united pictures with a powerful reading-glass. The two single images are hid by advancing the reading-glass, and the other two pictures are kept united with a less strain upon the eyes.

As very few people can use their eyes in this manner, some instrumental auxiliary became necessary, and it appears to us strange that the simplest method of doing this did not occur to Mr. Elliot and Mr. Wheatstone, who first thought of giving us the help of an instrument. By enabling the left eye to place an image of the left-hand picture upon the right-hand picture, as seen by the naked eye, we should have obtained a simple instrument, which might be called the *Monocular Stereoscope*, and which we shall have

occasion to describe. The same contrivance applied also to the right eye, would make the instrument *Binocular*. Another simple contrivance for assisting the eyes would have been to furnish them with a minute opera-glass, or a small astronomical telescope about an inch long, which, when held in the hand or placed in a pyramidal box, would unite the dissimilar pictures with the greatest facility and perfection. This form of the stereoscope will be afterwards described under the name of the *Opera-Glass Stereoscope*.

Description of the Ocular Stereoscope.

A stereoscope upon the principle already described, in which the eyes alone are the agent, was contrived, in 1834, by Mr. Elliot, as we have already had occasion to state. He placed the binocular pictures, described in Chapter I., at one end of a box, and without the aid either of lenses or mirrors, he obtained a landscape in perfect relief. I have examined this stereoscope, and have given, in Fig. 8, an

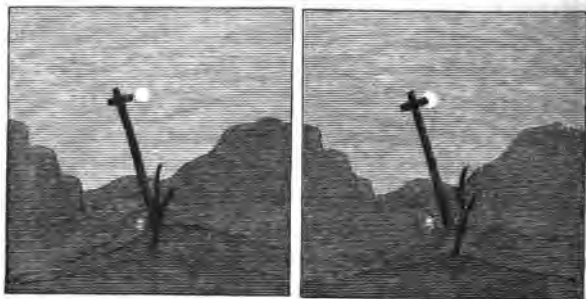


FIG. 8.

accurate though reduced drawing of the binocular pictures executed and used by Mr. Elliot. I have also united the

two original pictures by the convergency of the optic axes beyond them, and have thus seen the landscape in true relief. To delineate these binocular pictures upon stereoscopic principles was a bold undertaking, and establishes, beyond all controversy, Mr. Elliot's claim to the invention of the ocular stereoscope.

If we unite the two pictures in Fig. 8, by converging the optic axes to a point *nearer* the eye than the pictures, we shall see distinctly the stereoscopic relief, the moon being in the remote distance, the cross in the middle distance, and the stump of a tree in the foreground.

If we place the two pictures as in Fig. 9, which is the position they had in Mr. Elliot's box, and unite them,



FIG. 9.

by looking at a point beyond them we shall also observe the stereoscopic relief. In this position Mr. Elliot saw the relief without any effort, and even without being conscious that he was not viewing the pictures under ordinary vision. This tendency of the optic axes to a distant convergency is so rare that I have met with it only in one person.

As the relief produced by the union of such imperfect

pictures was sufficient only to shew the correctness of the principle, the friends to whom Mr. Elliot shewed the instrument thought it of little interest, and he therefore neither prosecuted the subject, nor published any account of his contrivance.

Mr. Wheatstone suggested a similar contrivance, without either mirrors or lenses. In order to unite the pictures by converging the optic axes to a point between them and the eye, he proposed to place them in a box to hide the lateral image and assist in making them unite with the naked eyes. In order to produce the union by looking at a point beyond the picture, he suggested the use of "a pair of tubes capable of being inclined to each other at various angles," the pictures being placed on a stand in front of the tubes. These contrivances, however, though auxiliary to the use of the naked eyes, were superseded by the Reflecting Stereoscope, which we shall now describe.

Description of the Reflecting Stereoscope.

This form of the stereoscope, which we owe to Mr. Wheatstone, is shewn in Fig. 10, and is described by him in the following terms :—"AA' are two plane mirrors, (whether of glass or metal is not stated,) about four inches square, inserted in frames, and so adjusted that their backs form an angle of 90° with each other ; these mirrors are fixed by their common edge against an upright B, or, which was less easy to represent in the drawing against the middle of a vertical board, cut away in such a manner as to allow the eyes to be placed before the two mirrors. c, c' are two sliding boards, to which are attached the upright boards D, D', which may thus be removed to different

distances from the mirrors. In most of the experiments hereafter to be detailed it is necessary that each upright board shall be at the same distance from the mirror which

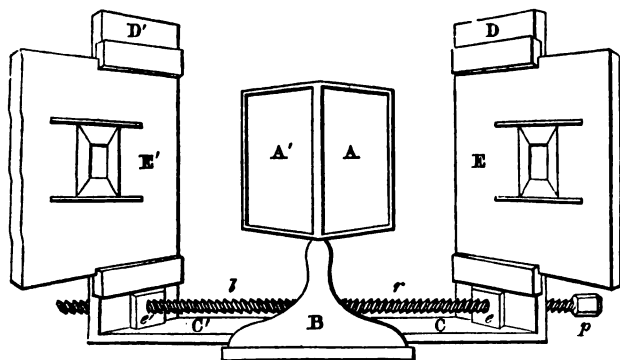


FIG. 10.

is opposite to it. To facilitate this double adjustment, I employ a right and a left-handed wooden screw, r , l ; the two ends of this compound screw pass through the nuts e , e' , which are fixed to the lower parts of the upright boards D , D' , so that by turning the screw pin p one way the two boards will approach, and by turning them the other they will recede from each other, one always preserving the same distance as the other from the middle line f ; E , E' are panels to which the pictures are fixed in such manner that their corresponding horizontal lines shall be on the same level; these panels are capable of sliding backwards or forwards in grooves on the upright boards D , D' . The apparatus having been described, it now remains to explain the manner of using it. The observer must place his eyes as near as possible to the mirrors, the right eye

before the right-hand mirror, and the left eye before the left-hand mirror, and he must move the sliding pannels E, E' to or from him till the two reflected images coincide at the intersection of the optic axes, and form an image of the same apparent magnitude as each of the component pictures. The picture will, indeed, coincide when the sliding pannels are in a variety of different positions, and, consequently, when viewed under different inclinations of the optic axes, but there is only one position in which the binocular image will be immediately seen single, of its proper magnitude, and without fatigue to the eyes, because in this position only the ordinary relations between the magnitude of the pictures on the retina, the inclination of the optic axes, and the adaptation of the eye to distinct vision at different distances, are preserved. In all the experiments detailed in the present memoir I shall suppose these relations to remain undisturbed, and the optic axes to converge about six or eight inches before the eyes.

“ If the pictures are all drawn to be seen with the same inclination of the optic axes the apparatus may be simplified by omitting the screw rl , and fixing the upright boards D, D' at the proper distance. The sliding pannels may also be dispensed with, and the drawings themselves be made to slide in the grooves.”

The figures to which Mr. Wheatstone applied this instrument were pairs of outline representations of objects of three dimensions, such as a cube, a cone, the frustum of a square pyramid, which is shewn on one side of E, E' in Fig. 10, and in other figures ; and he employed them, as he observes, “ for the purpose of illustration, for had either shading or colouring been introduced it might be supposed

that the effect was wholly or in part due to these circumstances, whereas, by leaving them out of consideration, no room is left to doubt that the entire effect of relief is owing to the simultaneous perception of the two monocular projections, one on each retina."

"Careful attention," he adds, "would enable an artist to draw and paint the two component pictures, so as to present to the mind of the observer, in the resultant perception, perfect identity with the object represented. Flowers, crystals, busts, vases, instruments of various kinds, &c., might thus be represented, *so as not to be distinguished by sight from the real objects themselves.*"

This expectation has never been realized, for it is obviously beyond the reach of the highest art to draw two copies of a flower or a bust with such accuracy of outline or colour as to produce "perfect identity," or anything approaching to it, "with the object represented."

Photography alone can furnish us with such representations of natural and artificial objects; and it is singular that neither Mr. Elliot nor Mr. Wheatstone should have availed themselves of the well-known photographic process of Mr. Wedgewood and Sir Humphry Davy, which, as Mr. Wedgewood remarks, wanted only "a method of preventing the unshaded parts of the delineation from being coloured by exposure to the day, to render the process as useful as it is elegant." When the two dissimilar photographs were taken they could have been used in the stereoscope in candle-light, or in faint day-light, till they disappeared, or permanent outlines of them might have been taken and coloured after nature.

Mr. Fox Talbot's beautiful process of producing perma-

nent photographs was communicated to the Royal Society in January 1839, but no attempt was made till some years later to make it available for the stereoscope.

In a chapter on binocular pictures, and the method of executing them in order to reproduce, with perfect accuracy, the objects which they represent, we shall recur to this branch of the subject.

Upon obtaining one of these reflecting stereoscopes as made by the celebrated optician, Mr. Andrew Ross, I found it to be very ill adapted for the purpose of uniting dissimilar pictures, and to be imperfect in various respects. Its imperfections may be thus enumerated :—

1. It is a clumsy and unmanageable apparatus, rather than an instrument for general use. The one constructed for me was $16\frac{1}{2}$ inches long, 6 inches broad, and $8\frac{1}{2}$ inches high.

2. The loss of light occasioned by reflection from the mirrors is very great. In all optical instruments where images are to be formed, and light is valuable, mirrors and specula have been discontinued. Reflecting microscopes have ceased to be used, but large telescopes, such as those of Sir W. and Sir John Herschel, Lord Rosse, and Mr. Lassell, were necessarily made on the reflecting principle, from the impossibility of obtaining plates of glass of sufficient size.

3. In using glass mirrors, of which the reflecting stereoscope is always made, we not only lose much more than half the light by the reflections from the glass and the metallic surface, and the absorbing power of the glass, but the images produced by reflection are made indistinct by the oblique incidence of the rays, which separates the image

produced by the glass surface from the more brilliant image produced by the metallic surface.

4. In all reflections, as Sir Isaac Newton states, the errors are greater than in refraction. With glass mirrors in the stereoscope, we have *four* refractions in each mirror, and the light transmitted through *twice* the thickness of the glass, which lead to two sources of error.

5. Owing to the exposure of the eye and every part of the apparatus to light, the eye itself is unfitted for distinct vision, and the binocular pictures become indistinct, especially if they are Daguerreotypes,¹ by reflecting the light incident from every part of the room upon their glass or metallic surface.

6. The reflecting stereoscope is inapplicable to the beautiful binocular slides which are now being taken for the lenticular stereoscope in every part of the world, and even if we cut in two those on paper and silver plate, they would give, in the reflecting instrument, *converse* pictures, the right-hand part of the picture being placed on the left-hand side, and *vice versa*.

7. With transparent binocular slides cut in two, we could obtain pictures by reflection that are not converse; but in using them, we would require to have two lights, one opposite each of the pictures, which can seldom be obtained in daylight, and which it is inconvenient to have at night.

Owing to these and other causes, the reflecting stereoscope never came into use, even after photography was capable of supplying binocular pictures.

As a set-off against these disadvantages, it has been

¹ Mr. Wheatstone himself says, "that it is somewhat difficult to render the two Daguerreotypes equally visible."—*Phil. Trans.*, 1852, p. 6.

averred that in the reflecting stereoscope we can use larger pictures, but this, as we shall shew in a future chapter, is altogether an erroneous assertion.

Description of the Lenticular Stereoscope.

Having found that the reflecting stereoscope, when intended to produce accurate results, possessed the defects which I have described, and was ill fitted for general use, both from its size and its price, it occurred to me that the union of the dissimilar pictures could be better effected by means of lenses, and that a considerable magnifying power would be thus obtained, without any addition to the instrument.

If we suppose A, B, Fig. 11, to be two portraits,—A a portrait of a gentleman, as seen by the left eye of a person

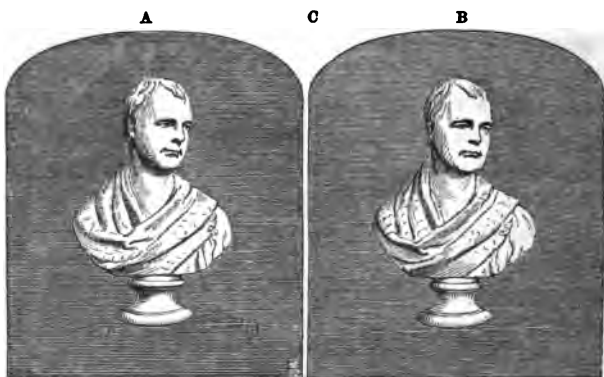


FIG. 11.

viewing him at the proper distance and in the best position, and B his portrait as seen by the right eye, the purpose of the stereoscope is to place these two pictures, or rather their images, one above the other. The method of

doing this by lenses may be explained, to persons not acquainted with optics, in the following manner :—

If we look at A with one eye through the *centre* of a convex glass, with which we can see it distinctly at the distance of 6 inches, which is called its *focal distance*, it will be seen in its place at A. If we now move the lens from *right to left*, the image of A will move towards B ; and when it is seen through the *right-hand* edge of the lens, the image of A will have reached the position C, half-way between A and B. If we repeat this experiment with the portrait B, and move the lens from *left to right*, the image of B will move towards A ; and when it is seen through the *left-hand* edge of the lens, the image of B will have reached the position C. Now, it is obviously by the *right-hand* half of the lens that we have transferred the image of A to C, and by the *left-hand* half that we have transferred the image of B to C. If we cut the lens in two, and place the halves—one in front of each picture at the distance of $2\frac{1}{2}$ inches—in the same position in which they were when A was transferred to C and B to C, they will stand as in Fig. 12, and we shall see the



FIG. 12.

portraits A and B united into one at C, and standing out in beautiful relief,—a result which will be explained in a subsequent chapter.

The same effect will be produced by quarter lenses, such as those shewn in Fig. 13. These lenses are cut into a round



FIG. 13.

or square form, and placed in tubes, as represented at B, L in Fig. 14, which is a drawing of the *Lenticular Stereoscope*.

This instrument consists of a pyramidal box, Fig. 14, blackened inside, and having a lid, CD, for the admission of light when required. The top of the box consists of two parts, in one of which is the right-eye tube, B, containing the lens G, Fig. 13, and in the other the left-eye tube, L, containing the lens H. The two parts which hold the lenses, and which form the top of the box, are often made to slide in grooves, so as to suit different persons whose eyes, placed at B, L, are more or less distant. This adjustment may be made by various pieces of mechanism. The simplest of these is a jointed parallelogram, moved by a screw forming its longer diagonal, and working in nuts fixed on the top of the box, so as to separate the semi-lenses, which follow the movements of the obtuse angles of the parallelogram. The tubes B, L move up and down, in order to suit eyes of different focal lengths, but they are prevented from turning round by a brass pin, which runs in a groove cut through the movable tube. Immediately below the eye-tubes B, L, there should be a groove, G, for the introduction of convex or concave lenses, when required for very long-

sighted or short-sighted persons, or for coloured glasses and other purposes.

If we now put the slide *A B*, Fig. 11, into the horizontal opening at *s*, turning up the sneck above *s* to prevent it

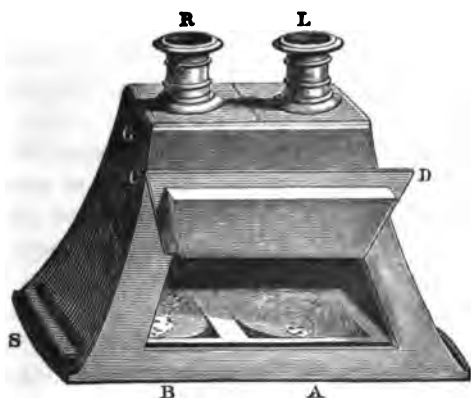


FIG. 14.

from falling out, and place ourselves behind *R*, *L*, we shall see, by looking through *R* with the right eye and *L* with the left eye, the two images *A*, *B* united in one, and in the same relief as the living person whom they represent. No portrait ever painted, and no statue ever carved, approximate in the slightest degree to the living reality now before us. If we shut the right eye *R* we see with the left eye *L* merely the portrait *A*, but it has now sunk into a flat picture, with only *monocular relief*. By closing the left eye we shall see merely the portrait *B*, having, like the other, only monocular relief, but a relief greater than the best-painted pictures can possibly have, when seen even

with one eye. When we open both eyes, the two portraits instantly start into all the roundness and solidity of life.

Many persons experience a difficulty in seeing the portraits single when they first look into a stereoscope, in consequence of their eyes having less power than common over their optic axes, or from their being more or less distant than two and a half inches, the average distance. The two images thus produced frequently disappear in a few minutes, though sometimes it requires a little patience and some practice to see the single image. We have known persons who have lost the power of uniting the images, in consequence of having discontinued the use of the instrument for some months ; but they have always acquired it again after a little practice.

If the portraits or other pictures are upon opaque paper or silver-plate, the stereoscope, which is usually held in the left hand, must be inclined so as to allow the light of the sky, or any other light, to illuminate every part of the pictures. If the pictures are on transparent paper or glass, we must shut the lid *CD*, and hold up the stereoscope against the sky or the artificial light, for which purpose the bottom of the instrument is made of glass finely ground on the outside, or has two openings, the size of each of the binocular pictures, covered with fine paper.

In using the stereoscope the observer should always be seated, and it is very convenient to have the instrument mounted like a telescope, upon a stand, with a weight and pulley for regulating the motion of the lid *CD*.

The lenticular stereoscope may be constructed of various materials and in different forms. I had them made originally of card-board, tin-plate, wood, and brass ; but wood

is certainly the best material when cheapness is not an object.

One of the earliest forms which I adopted was that which is shewn in Fig. 15, as made by M. Duboscq in Paris, and which may be called *stereoscopic spectacles*. The

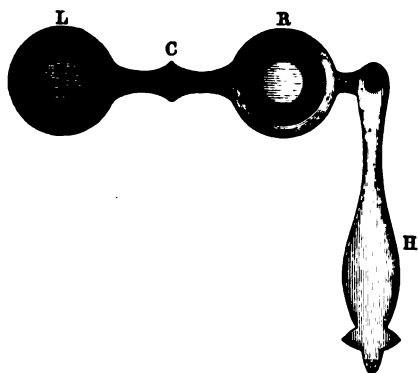


FIG. 15.

two-eye lenses L, R are held by the handle H, so that we can, by moving them to or from the binocular pictures, obtain distinct vision and unite them in one. The effect, however, is not so good as that which is produced when the pictures are placed in a box.

The same objection applies to a form otherwise more convenient, which consists in fixing a cylindrical or square rod of wood or metal to C, the middle point between L and R. The binocular slide having a hole in the middle between the two pictures is moved along this rod to its proper distance from the lenses.

Another form, analogous to this, but without the means of moving the pictures, is shewn in Fig. 16, as made by M. Duboscq. The adjustment is effected by moving the

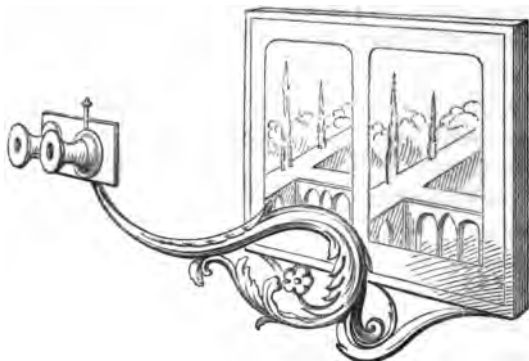


FIG. 16.

eye-pieces in their respective tubes, and by means of a screw-nut, shewn above the eye-pieces, they can be adapted to eyes placed at different distances from one another. The advantage of this form, if it is an advantage, consists in allowing us to use larger pictures than can be admitted into the box-stereoscope of the usual size. A box-stereoscope, however, of the same size, would have the same property and other advantages not possessed by the open instrument.

Another form of the lenticular stereoscope, under the name of the *cosmorama* stereoscope, has been adopted by Mr. Knight. The box is rectangular instead of pyramidal, and the adjustment to distinct vision is made by pulling out or pushing in a part of the box, instead of the common and better method of moving each lens

separately. The illumination of the pictures is made in the same manner as in the French instrument, called the *cosmorama*, for exhibiting dissolving views. The lenses are large in surface, which, without any reason, is supposed to facilitate the view of the binocular pictures, and the instrument is supported in a horizontal position upon a stand. There is no contrivance for adjusting the distance of the lenses to the distance between the eyes, and owing to the quantity of light which gets into the interior of the box, the stereoscopic picture is injured by false reflections, and the sensibility of the eyes diminished. The exclusion of all light from the eyes, and of every other light from the picture but that which illuminates it, is essentially necessary to the perfection of stereoscopic vision.

When by means of any of these instruments we have succeeded in forming a single image of the two pictures, we have only, as I have already explained, placed the one picture above the other, in so far as the stereoscope is concerned. It is by the subsequent action of the two eyes that we obtain the desired relief. Were we to unite the two pictures when transparent, and take a copy of the combination by the best possible camera, the result would be a blurred picture, in which none of the points or lines of the one would be united with the points or lines of the other ; but were we to look at the combination with both eyes the blurred picture would start into relief, the eyes uniting in succession the separate points and lines of which it is composed.

Now, since, in the stereoscope, when looked into with two eyes, we see the picture in relief with the same accu-

racy as, in ordinary binocular vision, we see the same object in relief by uniting on the retina two pictures exactly the same as the binocular ones, the mere statement of this fact has been regarded as the theory of the stereoscope. We shall see, however, that it is not, and that it remains to be explained, more minutely than we have done in Chapter III., both how we see objects in relief in ordinary binocular vision, and how we see them in the same relief by uniting ocularly, or in the stereoscope, two dissimilar images of them.

Before proceeding, however, to this subject, we must explain the manner in which half and quarter lenses unite the two dissimilar pictures.

In Fig. 17 is shewn a semi-lens MN , with its section

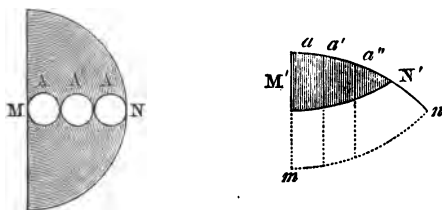


FIG. 17.

$M'N'$. If we look at any object successively through the portions $AA'A''$ in the semi-lens MN , corresponding to $aa'a''$ in the section $M'N'$, which is the same as in a quarter-lens, the object will be magnified equally in all of them, but it will be more displaced, or more refracted, towards N , by looking through A' or a' than through A or a , and most of all by looking through A'' or a'' , the refraction being greatest at A'' or a'' , less at A' or a' , and still less at A or a . By means of a semi-lens, or a quarter of a lens of the size of MN , we can,

with an aperture of the size of Δ , obtain three different degrees of displacement or refraction, without any change of the magnifying power.

If we use a thicker lens, as shewn at $m'n'm$, keeping the curvature of the surface the same, we increase the refracting angle at its margin $n'n$, we can produce any degree of displacement we require, either for the purposes of experiment, or for the duplication of large binocular pictures.

When two half or quarter lenses are used as a stereoscope, the displacement of the two pictures is produced in the manner shewn in Fig. 18, where LL is the lens for the left eye E , and $L'L'$ that for the right eye E' , placed so that the middle points, no , $n'o'$, of each are $2\frac{1}{2}$ inches distant, like the two eyes. The two binocular pictures which are to be united are shewn at ab , ΔB , and placed at nearly the same distance. The pictures being fixed in the focus of the lenses, the pencils ano , $\Delta'n'o'$, bno , $B'n'o'$, will be refracted at the points n , o , n' , o' , and at their points of incidence on the second surface, so as to enter the eyes, E , E' , in parallel directions, though not shewn in the Figure. The points a , Δ , of one of the pictures, will therefore be seen distinctly in the direction of the refracted ray—that is, the pencils an , ao , issuing from a' , will be seen as if they came from a' , and the pencils bn , bo , as if they came from b' , so that ab will be transferred by refraction to $a'b'$. In like manner, the picture ΔB will be transferred by refraction to $\Delta'B'$, and thus united with $a'b'$.

The pictures ab , ΔB thus united are merely circles, and will therefore be seen as a single circle at $\Delta'B'$. But if we suppose ab to be the base of the frustum of a cone, and cd its summit, as seen by the left eye, and the circles ΔB , CD

to represent the base and summit of the same solid as seen by the right eye, then it is obvious that when the pictures of

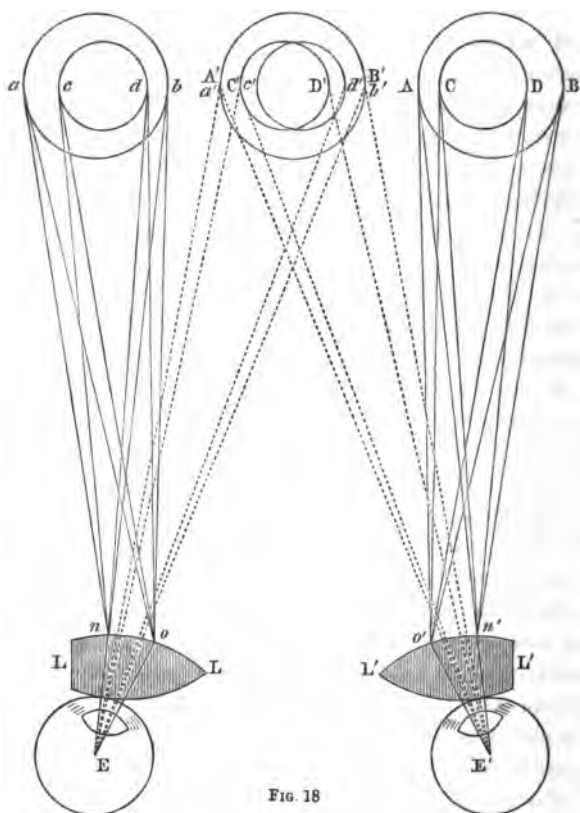


FIG. 18

cd and CD are similarly displaced or refracted by the lenses $LL' L'L'$, so that cc' is equal to AA' and DD' to BB' , the circles will not be united, but will overlap one another as at

$c'd'$, $c'd$, in consequence of being carried *beyond* their place of union. The eyes, however, will instantly unite them into one by converging their axes to a remoter point, and the united circles will rise from the paper, or from the base $A'B'$, and place the single circle at the point of convergence, as the summit of the frustum of a hollow cone whose base is $A'B'$. If $c'd$, CD had been *farther* from one another than ab , AB , as in Figs. 20 and 21, they would still have overlapped though not carried up to their place of union. The eyes, however, will instantly unite them by converging their axes to a *nearer* point, and the united circles will rise from the paper, or from the base AB , and form the summit of the frustum of a *raised* cone whose base is $A'B'$.

In the preceding illustration we have supposed the solid to consist only of a base and a summit, or of parts at *two* different distances from the eye; but what is true of two distances is true of any number, and the instant that the two pictures are combined by the lenses they will exhibit in relief the body which they represent. If the pictures are refracted too little, or if they are refracted too much, so as not to be united, their tendency to unite is so great, that they are soon brought together by the increased or diminished convergency of the optic axes, and the stereoscopic effect is produced. Whenever two pictures are seen, no relief is visible; when only one picture is distinctly seen, the relief must be complete.

In the preceding diagram we have not shewn the refraction at the second surface of the lenses, nor the parallelism of the rays when they enter the eye,—facts well known in elementary optics.

CHAPTER V.

ON THE THEORY OF STEREOSCOPIC VISION.

HAVING, in the preceding chapter, described the ocular, the reflecting, and the lenticular stereoscopes, and explained the manner in which the two binocular pictures are combined or laid upon one another in the last of these instruments, we shall now proceed to consider the theory of stereoscopic vision.

In order to understand how the two pictures, when placed the one above the other, rise into relief, we must first explain the manner in which a solid object itself is, in ordinary vision, seen in relief, and we shall then shew how this process takes place in the two forms of the ocular stereoscope, and in the lenticular stereoscope. For this purpose, let $ABCD$, Fig. 19, be a section of the frustum of a cone, that is, a cone with its top cut off by a plane cdg , and having $AEBG$ for its base. In order that the figure may not be complicated, it will be sufficient to consider how we see, with two eyes, L and R , the cone as projected upon a plane passing through its summit cdg . The points L, R being the points of sight, draw the lines RA, RB , which will cut the plane on which the projection is to be made in the points a, b , so that ab will represent the line AB , and a circle, whose diameter is ab , will represent the base of the cone, as seen by the right

eye R. In like manner, by drawing LA, LB , we shall find that $A'B'$ will represent the line AB , and a circle, whose

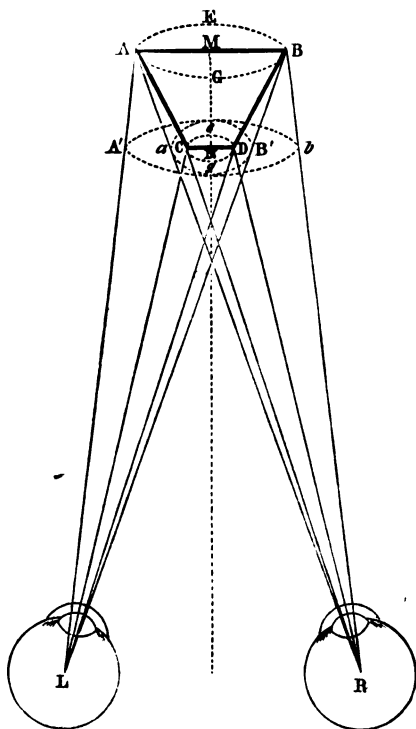


FIG. 19.

diameter is $A'B'$, the base $AEBG$, as seen by the left eye. The summit, $cedg$, of the frustum being in the plane of projection, will be represented by the circle $cedg$. The representation of the frustum $ABCD$, therefore, upon a plane

surface, as seen by the left eye L, consists of two circles, whose diameters are AB, CD ; and, as seen by the right eye, of other two circles, whose diameters are ab, cd , which, in Fig. 20, are represented by AB, CD , and ab, cd . These

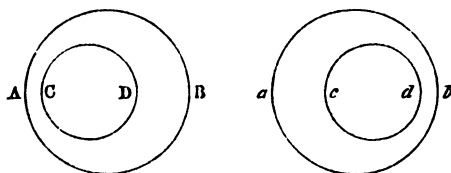


FIG. 20.

plane figures being also the representation of the solid on the retina of the two eyes, how comes it that we see the solid and not the plane pictures? When we look at the point B, Fig. 19, with both eyes, we converge upon it the optic axes LB, RB, and we therefore see the point single, and at the distances LB, RB from each eye. When we look at the point D, we withdraw the optic axes from B, and converge them upon D. We therefore see the point D single, and at the distances LD, RD from each eye; and in like manner the eyes run over the whole solid, seeing every point single and distinct upon which they converge their axes, and at the distance of the point of convergence from the observer. During this rapid survey of the object, the whole of it is seen distinctly as a solid, although every point of it is seen double and indistinct, excepting the point upon which the axes are for the instant converged.

From these observations it is obvious, that when we look with both eyes at any solid or body in relief, *we see more of the right side of it by the right eye, and more of the left side*

of it by the left eye. The right side of the frustum $ABCD$, Fig. 19, is represented by the line Db , as seen by the right eye, and by the shorter line DE' , as seen by the left eye. In like manner, the left side AC is represented by CA' , as seen by the left eye, and by the shorter line CA' , as seen by the right eye.

When the body is hollow, like a wine glass, *we see more of the right side with the left eye, and more of the left side with the right eye.*

If we now separate, as in Fig. 20, the two projections shewn together on Fig. 19, we shall see that the two summits, CD , cd , of the frustum are farther from one another than the more distant bases, AB , ab , and it is true generally that *in the two pictures of any solid in relief, the similar parts that are near the observer are more distant in the two pictures than the remoter parts, when the plane of perspective is beyond the object.* In the binocular picture of the human face the distance between the two noses is greater than the distance between the two right or left eyes, and the distance between the two right or left eyes greater than the distance between the two remoter ears.

We are now in a condition to explain the process by which, with the eyes alone, we can see a solid in relief by uniting the right and left eye pictures of it,—or the theory ocular stereoscope. In order to obtain the proper relief we must place the right eye picture on the left side, and the left eye picture on the right side, as shewn in Fig. 21, by the pictures $ABCD$, $abcd$, of the frustum of a cone, as obtained from Fig. 19.

In order to unite these two dissimilar projections, we must converge the optical axes to a point nearer the ob-

server, or look at some point about m . Both pictures will immediately be doubled. An image of the figure ab will advance towards P , and an image of AB will likewise

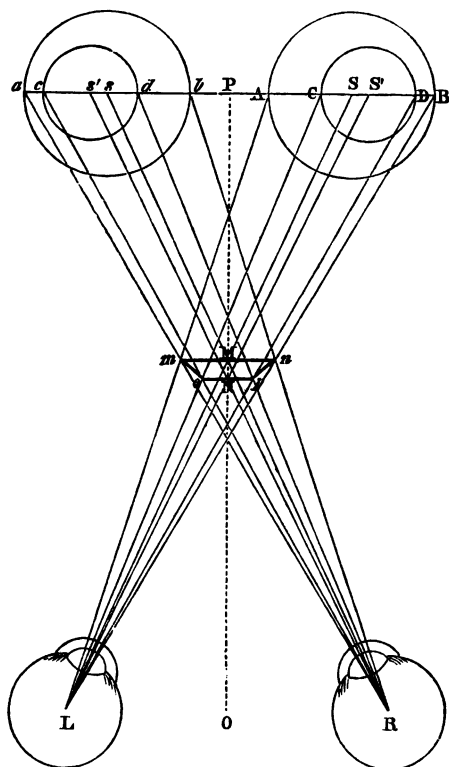


FIG. 21.

advance towards P ; and the instant these images are united, the frustum of a cone, which they represent, will appear in

relief at MN , the place where the optic axes meet or cross each other. At first the solid figure will appear in the middle, between the two pictures from which it is formed and of the same size, but after some practice it will appear smaller and nearer the eye. Its smallness is an optical illusion, as it has the same angle of apparent magnitude as the plane figures, namely, $mnL = ABL$; but its position at MN is a reality, for if we look at the point of our finger held beyond M the solid figure will be seen nearer the eye. The difficulty which we experience in seeing it of the size and in the position shewn in Fig. 21, arises from its being seen along with its two plane representations, as we shall prove experimentally when we treat in a future chapter of the union of similar figures by the eye.

The two images being thus superimposed, or united, we shall now see that the combined images are seen in relief in the very same way that in ordinary vision we saw the real solid, $ABCD$, Fig. 19, in relief, by the union of the two pictures of it on the retina. From the points A, B, C, D, a, b, c, d , draw lines to L and R , the centres of visible direction of each eye, and it will be seen that the circles AB, ab , representing the base of the cone, can be united by converging the optical axes to points in the line mn , and that the circles CD, cd , which are more distant, can be united only by converging the optic axes to points in the line op . The points A, a , for example, united by converging the axes to m , are seen at that point single; the points B, b at n single, the points C, c at o single, the points D, d at p single, the centres s, s of the base at M single, and the centres s', s' of the summit plane at N single. Hence the eyes L and R see the combined pictures at

MN in relief, exactly in the same manner as they saw in relief the original solid MN in Fig. 19.

In order to find the height MN of the conical frustum thus seen, let D = distance OP ; $d = ss$, the distance of the two points united at M ; $d' = s's'$, the distance of the two points united at N ; and $C = LE = 2\frac{1}{2}$ inches, the distance of the eyes. Then we have—

$$\begin{aligned} MP &= \frac{D d}{C + d} \\ NP &= \frac{D d'}{C + d'}, \text{ and} \\ MN &= \frac{D d}{C + d} - \frac{D d'}{C + d'}. \end{aligned}$$

If $D = 9.24$ inches,
 $C = 2.50$, then
 $d = 2.14$,
 $d' = 2.42$, and
 $MN = 0.283$, the height of the cone.

When $C = d$, $MP = \frac{D C}{2 C}$.

As the summit plane op rises above the base mn by the successive convergency of the optic axes to different points in the line ONP , it may be asked how it happens that the conical frustum still appears a solid, and the plane op where it is, when the optic axes are converged to points in the line MMN , so as to see the base distinctly? The reason of this is that the rays emanate from op exactly in the same manner, and form exactly the same image of it, on the two retinas as if it were the summit CD , Fig. 19, of the real solid when seen with both eyes. The only effect of the advance of the point of convergence from N to M is to throw the image of N a little to the *right* side of the

optic axis of the left eye, and a little to the *left* of the optic axis of the right eye. The summit plane op will therefore retain its place, and will be seen slightly doubled and indistinct till the point of convergence again returns to it.

It has been already stated that the two dissimilar pictures may be united by converging the optical axes to a point beyond them. In order to do this, the distance ss' of the pictures, Fig. 21, must be greatly less than the distance of the eyes L, R , in order that the optic axes, in passing through similar points of the two plane pictures, may meet at a moderate distance beyond them. In order to explain how the relief is produced in this case, let AB, CD, ab, cd , Fig. 22, be the dissimilar pictures of the frustum of a cone whose summit is CD , as seen by the right eye, and cd as seen by the left eye. From L and R , as before, draw lines through all the leading points of the pictures, and we shall have the points A, a united at m , the points B, b at n , the points C, c at o , and the points D, d at p , the points s, s at M , and the points s', s' at N , forming the cone $mno p$, with its base mn towards the observer, and its summit op more remote. If the cone had been formed of lines drawn from the outline of the summit to the outline of the base, it would now appear *hollow*, the inside of it being seen in place of the outside as before. If the pictures AB, ab are made to change places the combined picture would be in relief, while in the case shewn in Fig. 21 it would have been hollow. Hence the *right-eye* view of any solid must be placed on the *left* hand, and the *left-eye* view of it on the *right* hand, when we wish to obtain it in relief by converging the optic axes to a point between the pictures and the eye, and *vice versa* when we wish to obtain

it in relief by converging the optic axes to a point beyond the pictures. In every case when we wish the combined

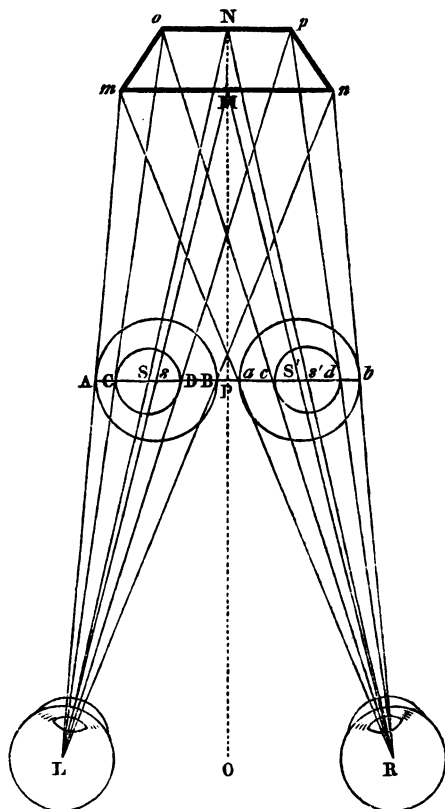


FIG. 22.

pictures to represent a *hollow*, or the converse of relief, their places must be exchanged.

In order to find the height MN , or rather the depth of the cone in Fig. 22, let D, d, c, c' represent the same quantities as before, and we shall have

$$MP = \frac{Dd}{c-d}$$

$$NP = \frac{Dd'}{c-d'}, \text{ and}$$

$$OP = \frac{Dd'}{c-d'} - \frac{Dd}{c-d}$$

When D, c, d, d' have the same values as before, we shall have

$$MN = 18.7 \text{ feet !}$$

When $c = d$, MP will be infinite.

We have already explained how the two binocular pictures are combined or laid upon one another in the lenticular stereoscope. Let us now see how the relief is obtained. The two plane pictures $abcd, ABCD$, in Fig. 18, are, as we have already explained, combined or simply laid upon one another by the lenses $LL, L'L'$, and in this state are shewn by the middle circles at Aab, cCd . The images of the bases AB, ab of the cone are accurately united in the double base AB, ab , but the summits of the conical frustum remain separate, as seen at $C'D', c'd'$. It is now the business of the eyes to unite these, or rather to make them appear as united. We have already seen how they are brought into relief when the summits are refracted so as to pass one another, as in Fig. 18. Let us therefore take the case shewn in Fig. 20, where the summits CD, cd are more distant than the bases AB, ab . The union of these figures is instantly effected, as shewn in Fig. 23, by converging the optic axes to points m and n successively, and thus uniting c and c and D and d , and making these points of the summit plane appear at m and n , the

points of convergence of the axes Lm , Rm , and Ln , Rn . In like manner, every pair of points in the summit

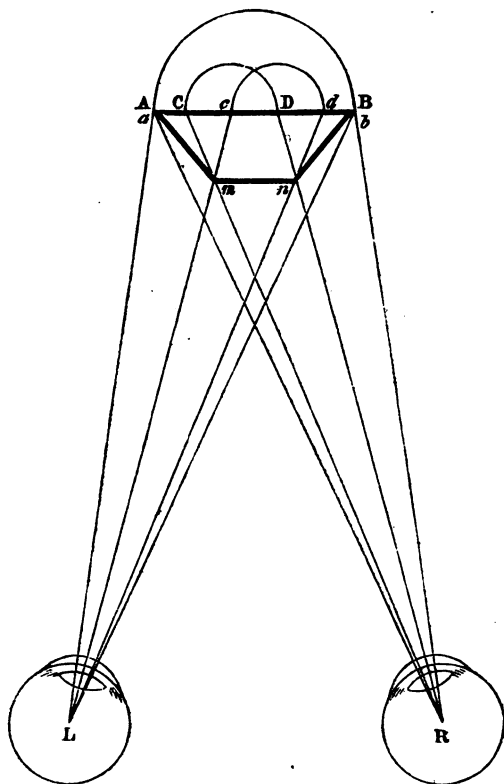


FIG. 23.

plane, and in the sides Am , Bn of the frustum, are converged to points corresponding to their distance from the base AB of the original solid frustum, from which the plane

pictures $ABCD$, $abcd$, were taken. We shall, therefore, see in relief the frustum of a cone whose section is $A m n B$.

The theory of the stereoscope may be expressed and illustrated in the following manner, without any reference to binocular vision :—

1. When a drawing of any object or series of objects is executed on a plane surface from *one point of sight*, according to the principles of geometrical perspective, every point of its surface that is visible from the point of sight will be represented on the plane.

2. If another drawing of the same object or series of objects is similarly executed on the same plane from a *second point of sight*, sufficiently distant from the first to make the two drawings separate without overlapping, every point of its surface visible from this second point of sight will also be represented on the plane, so that we shall have two different drawings of the object placed, at a short distance from each other, on the same plane.

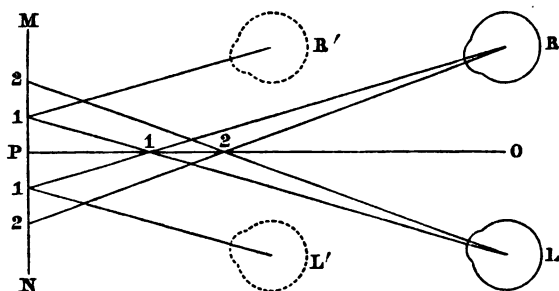


FIG. 24.

3. Calling these different points of the object 1, 2, 3, 4, &c., it will be seen from Fig. 24, in which L , R are the

two points of sight, that the distances 1, 1, on the plane MN , of any pair of points in the two pictures representing the point 1 of the object, will be to the distance of any other pair 2, 2, representing the point 2, as the distances $1'P$, $2'P$ of the points of the object from the plane MN , multiplied inversely by the distances of these points from the points of sight L , R , or the middle point o between them.

4. If the sculptor, therefore, or the architect, or the mechanist, or the surveyor, possesses two such pictures, either as drawn by a skilful artist or taken photographically, he can, by measuring the distances of every pair of points, obtain the relief or prominence of the original point, or its distance from the plane MN or AB ; and without the use of the stereoscope, the sculptor may model the object from its plane picture, and the distances of every point from a given plane. In like manner, the other artists may determine distances in buildings, in machinery, and in the field.

5. If the distance of the points of sight is equal to the distance of the eyes L , R , the two plane pictures may be united and raised into relief by the stereoscope, and thus give the sculptor and other artists an accurate model, from which they will derive additional aid in the execution of their work.

6. In stereoscopic vision, therefore, when we join the points 1, 1 by converging the optic axes to $1'$ in the line PO , and the points 2, 2 by converging them to $2'$ in the same line, we place these points at the distances $o1$, $o2$, and *see the relief*, or the various differences of distance which the sculptor and others obtained by the method which we have described.

7. Hence we infer, that if the stereoscopic vision of relief had never been thought of, the principles of the instrument are involved in the geometrical relief which is embodied in the two pictures of an object taken from two points of sight, and in the prominence of every part of it obtained geometrically.

CHAPTER VI.

ON THE UNION OF SIMILAR PICTURES IN BINOCULAR
VISION.

IN uniting by the convergency of the optic axes two dissimilar pictures, as shewn in Fig. 18, the solid cone MN ought to appear at MN much nearer the observer than the pictures which compose it. I found, however, that it never took its right position in absolute space, the base MN of the solid seeming to rest on the same plane with its constituent pictures AB , ab , whether it was seen by converging the axes as in Fig. 18 or in Fig. 22. Upon inquiring into the reason of this I found that the disturbing cause was simply the simultaneous perception of other objects in the same field of view whose distance was known to the observer.

In order to avoid all such influences I made experiments on large surfaces covered with similar plane figures, such as flowers or geometrical patterns upon paper-hangings and carpets. These figures being always at equal distances from each other, and almost perfectly equal and similar, the coalescence of any pair of them, effected by directing the optic axes to a point between the paper-hanging and the eye, is accompanied by the instantaneous coalescence of

them all. If we, therefore, look at a papered wall without pictures, or doors, or windows, or even at a considerable portion of a wall, at the distance of three feet, and unite two of the figures,—two flowers, for example, at the distance of twelve inches from each other horizontally, the whole wall or visible portion of it will appear covered with flowers as before, but as each flower is now composed of two flowers united at the point of convergence of the optic axes, *the whole papered wall with all its flowers will be seen suspended in the air at the distance of six inches from the observer!* At first the observer does not decide upon the distance of the suspended wall from himself. It generally advances slowly to its new position, and when it has taken its place it has a very singular character. The surface of it seems slightly curved. It has a silvery transparent aspect. It is more beautiful than the real paper, which is no longer seen, and it moves with the slightest motion of the head. If the observer, who is now three feet from the wall, retires from it, the suspended wall of flowers will follow him, moving farther and farther from the real wall, and also, but very slightly, farther and farther from the observer. When he stands still, he may stretch out his hand and place it on the other side of the suspended wall, and even hold a candle on the other side of it to satisfy himself that the ghost of the wall stands between the candle and himself.

In looking attentively at this strange picture some of the flowers have the aspect of real flowers. In some the stalk retires from the plane of the picture. In others it rises from it. One leaf will come farther out than another. One coloured portion, *red*, for example, will be more pro-

minent than the *blue*, and the flower will thus appear thicker and more solid, like a real flower compressed, and deviating considerably from the plane representation of it as seen by one eye. All this arises from slight and accidental differences of distance in similar or corresponding parts of the united figures. If the distance, for example, between two corresponding leaves is greater than the distance between other two corresponding leaves, then the two first when united will appear nearer the eye than the other two, and hence the appearance of a flower in low relief, is given to the combination.

In continuing our survey of the suspended image another curious phenomenon often presents itself. A part of one, or even two pieces of paper, and generally the whole length of them from the roof to the floor, will retire behind the general plane of the image, as if there were a recess in the wall, or rise above it as if there were a projection, thus displaying on a large scale the imperfection in the workmanship which otherwise it would have been difficult to discover. This phenomenon, or defect in the work, arises from the paper-hanger having cut off too much of the margin of one or more of the adjacent stripes or pieces, or leaving too much of it, so that, in the first case, when the two halves of a flower are joined together, part of the middle of the flower is left out, and hence, when this defective flower is united binocularly with the one on the right hand of it, and the one on the left hand united with the defective one, the united or corresponding portion being at a less distance, will appear farther from the eye than those parts of the suspended image which are composed of complete flowers. The opposite effect will be produced

when the two portions of the flowers are not brought together, but separated by a small space. All these phenomena may be seen, though not so conveniently, with a carpet from which the furniture has been removed. We have, therefore, an accurate method of discovering defects in the workmanship of paper-hangers, carpet-makers, painters, and all artists whose profession it is to combine a series of similar patterns or figures to form an uniformly ornamented surface. The smallest defect in the similarity or equality of the figures or lines which compose a pattern, and any difference in the distance of single figures is instantly detected, and what is very remarkable a small inequality of distance in a line perpendicular to the axis of vision, or in one dimension of space, is exhibited in a magnified form at a distance coincident with the axis of vision, and in an opposite dimension of space.

A little practice will enable the observer to realize and to maintain the singular binocular vision which replaces the real picture.¹ The occasional retention of the picture after one eye is closed, and even after both have been closed and quickly reopened, shews the influence of time over the evanescence as well as over the creation of this class of phenomena. On some occasions, a singular effect is produced. When the flowers or figures on the paper are distant *six* inches, we may either unite *two* six inches distant, or *two* twelve inches distant, and so on. In the latter case, when the eyes have been accustomed to survey the suspended picture, I have found that, after shutting or opening them, I neither saw the picture formed by the two

¹ A sheet of Queen's heads may be advantageously used to accustom the eyes to the union of similar figures.

flowers *twelve* inches distant, nor the papered wall itself, but a picture formed by uniting all the flowers *six* inches distant ! The binocular centre (the point to which the optic axes converged, and consequently the locality of the picture) had shifted its place, and instead of advancing to the real wall and seeing it, it advanced exactly as much as to unite the nearest flowers, just as in a ratchet wheel, when the detent stops one tooth at a time ; or, to speak more correctly, the binocular centre advanced in order to relieve the eyes from their strain, and when the eyes were opened, it had just reached that point which corresponded with the union of the flowers *six* inches distant.

We have already seen, as shewn in Fig. 22, that when we fix the binocular centre, that is, converge the optic axes on a point beyond the dissimilar pictures, so as to unite them, they rise into relief as perfectly as when the binocular centre, as shewn in Fig. 18, is fixed between the pictures used and the eye. In like manner we may unite similar pictures, but, owing to the opacity of the wall and the floor, we cannot accomplish this with paper-hangings and carpets. The experiment, however, may be made with great effect by looking through transparent patterns cut out of paper or metal, such as those in zinc which are used for larders and other purposes. Particular kinds of trellis-work, and windows with small squares or rhombs of glass, may also be used, and, what is still better, a screen might be prepared, by cutting out the small figures from one or more pieces of paper-hangings. The readiest means, however, of making the experiment, is to use the cane bottom of a chair, which often exhibits a succession of octagons with small luminous spaces between them. To do this, place the back

of the chair upon a table, the height of the eye either when sitting or standing, so that the cane bottom with its luminous pattern may have a vertical position, as shewn in Fig. 25, where MN is the real bottom of the chair with its

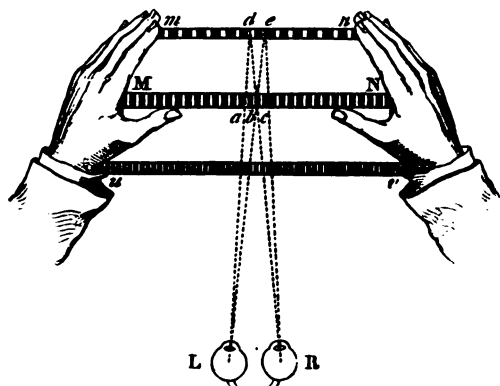


FIG. 25.

openings, which generally vary from half an inch to three-fourths. Supposing the distance to be half an inch, and the eyes, L , R , of the observer 12 inches distant from MN , let Lad , Lbe be lines drawn through the centres of two of the open spaces a , b , and Rbd , Rce lines drawn through the centres of b and c , and meeting Lad , Lbe at d and e , d being the binocular centre to which the optic axes converge when we look at it through a and b , and c the binocular centre when we look at it through b and c . Now, the right eye, R , sees the opening b at d , and the left eye sees the opening a at d , so that the image at d of the opening consists of the similar images of a and b united, and so on with all the

rest ; so that the observer at L, R no longer sees the real pattern MN , but an image of it suspended at mn , three inches behind MN . If the observer now approaches MN , the image mn will approach to him, and if he recedes, mn will recede also, being $1\frac{1}{2}$ inches behind MN when the observer is *six* inches before it, and *twelve* inches behind MN when the observer is *forty-eight* inches before it, the image mn moving from mn with a velocity one-fourth of that with which the observer recedes.

The observer resuming the position in the figure where his eyes, L, R , are *twelve* inches distant from MN , let us consider the important results of this experiment. If he now grasps the cane bottom at MN , his thumbs pressing upon MN , and his fingers trying to grasp mn , he will then *feel what he does not see, and see what he does not feel* ! The real pattern is absolutely invisible at MN , where he feels it, and it stands fixed at mn . The fingers may be passed through and through between the real and the false image, and beyond it,—now seen on this side of it, now in the middle of it, and now on the other side of it. If we next place the palms of each hand upon MN , the real bottom of the chair, feeling it all over, the result will be the same. No knowledge derived from touch—no measurement of real distance—no actual demonstration from previous or subsequent vision, that there is a real solid body at MN , and nothing at all at mn , will remove or shake the infallible conviction of the sense of sight that the cane bottom is at mn , and that dL or dR is its real distance from the observer. If the binocular centre be now drawn back to MN , the image *seen* at mn will disappear, and the real object be *seen and felt* at MN . If the binocular centre be brought

further back to f , that is, if the optic axes are converged to a point nearer the observer than the object, as illustrated by Fig. 18, the cane bottom MN will again disappear, and will be seen at uv , as previously explained.

This method of uniting small similar figures is more easily attained than that of doing it by converging the axes to a point between the eye and the object. It puts a very little strain upon the eyes, as we cannot thus unite figures the distance of whose centre is equal to or exceeds $2\frac{1}{2}$ inches, as appears from Fig. 22.

In making these experiments, the observer cannot fail to be struck with the remarkable fact, that though the openings MN , mn , uv , have all the same apparent or angular magnitude, that is, subtend the same angle at the eye, viz., dLc , dRc , yet those at mn appear larger, and those at uv smaller, than those at MN . If we cause the image mn to recede and approach to us, the figures in mn will invariably *increase as they recede*, and those in uv diminish as they approach the eye, and their *visual magnitudes*, as we may call them, will depend on the respective distances at which the observer, whether right or wrong in his estimate, conceives them to be placed,—a result which is finely illustrated by the different size of the moon when seen in the horizon and in the meridian. The fact now stated is a general one, which the preceding experiments demonstrate; and though our estimate of magnitude thus formed is erroneous, yet it is one which neither reason nor experience is able to correct.

It is a curious circumstance, that, previous to the publication of these experiments, no examples have been recorded of false estimates of the distance of near objects in conse-

quence of the *accidental* binocular union of similar images. In a room where the paper-hangings have a small pattern, a short-sighted person might very readily turn his eyes on the wall when their axes converged to some point between him and the wall, which would unite one pair of the similar images, and in this case he would see the wall nearer him than the real wall, and moving with the motion of his head. In like manner a long-sighted person, with his optical axes converged to a point beyond the wall, might see an image of the wall more distant, and moving with the motion of his head ; or a person who has taken too much wine, which often fixes the optical axes in opposition to the will, might, according to the nature of his sight, witness either of the illusions above mentioned.

Illusions of both these kinds, however, have recently occurred. A friend to whom I had occasion to shew the experiments, and who is short-sighted, mentioned to me that he had on two occasions been greatly perplexed by the vision of these suspended images. Having taken too much wine, he saw the wall of a papered room suspended near him in the air ; and on another occasion, when kneeling, and resting his arms on a cane-bottomed chair, he had fixed his eyes on the carpet, which had accidentally united the two images of the open octagons, and thrown the image of the chair bottom beyond the plane on which he rested his arms.

After hearing my paper on this subject read at the Royal Society of Edinburgh, Professor Christison communicated to me the following interesting case, in which one of the phenomena above described was seen by himself :—"Some years ago," he observes, "when I resided in a house where several

rooms are papered with rather formally recurring patterns, and one in particular with stars only, I used occasionally to be much plagued with the wall suddenly standing out upon me, and waving, as you describe, with the movements of the head. I was sensible that the cause was an error as to the point of union of the visual axes of the two eyes; but I remember it sometimes cost me a considerable effort to rectify the error; and I found that the best way was to increase still more the deviation in the first instance. As this accident occurred most frequently while I was recovering from a severe attack of fever, I thought my near-sighted eyes were threatened with some new mischief; and this opinion was justified in finding that, after removal to my present house, where, however, the papers have no very formal pattern, no such occurrence has ever taken place. The reason is now easily understood from your researches."¹

Other cases of an analogous kind have been communicated to me; and very recently M. Soret of Geneva, in looking through a trellis-work in metal stretched upon a frame, saw the phenomenon represented in Fig. 25, and has given the same explanation of it which I had published long before.²

Before quitting the subject of the binocular union of *similar* pictures, I must give some account of a series of curious phenomena which I observed by uniting the images of lines meeting at an angular point when the eye is placed at different heights above the plane of the paper, and at different distances from the angular point.

¹ See *Edin. Transactions*, 1846, vol. xv. p. 663, and *Phil. Mag.*, May 1847, vol. xxx. p. 305.

² *Bibl. Universelle*, October 1855, p. 136.

Let AC , BC , Fig. 26, be two lines meeting at C , the plane passing through them being the plane of the paper, and let them be viewed by the eyes successively placed at

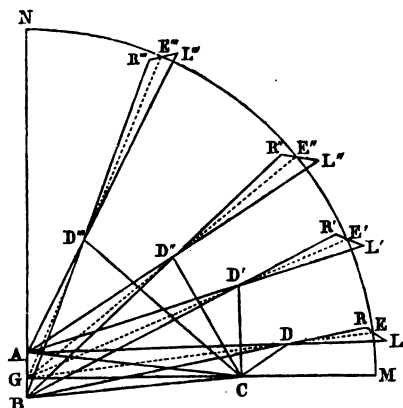


FIG. 26.

E'' , E' , E , and E , at different heights in a plane, GMN , perpendicular to the plane of the paper. Let R be the right eye, and L the left eye, and when at E'' , let them be strained so as to unite the points A , B . The united image of these points will be seen at the binocular centre D'' , and the united lines AC , BC , will have the position $D''C$. In like manner, when the eye descends to E' , E , the united image $D''C$ will rise and diminish, taking the positions $D'C$, $D'C$, $D'C$, till it disappears on the line CM , when the eyes reach M . If the eye deviates from the vertical plane GMN , the united image will also deviate from it, and is always in a plane passing through the common axis of the two eyes and the line GM .

If at any altitude EM , the eye advances towards ACB in the line EG , the binocular centre D will also advance towards ACB in the line EG , and the image DC will rise, and become shorter as its extremity D moves along DG , and, after passing the perpendicular to GE , it will increase in length. If the eye, on the other hand, recedes from ACB in the line GE , the binocular centre D will also recede, and the image DC will descend to the plane CM , and increase in length.

The preceding diagram is, for the purpose of illustration, drawn in a sort of perspective, and therefore does not give the true positions and lengths of the united images. This defect, however, is remedied in Fig. 27, where E, E', E'', E'''

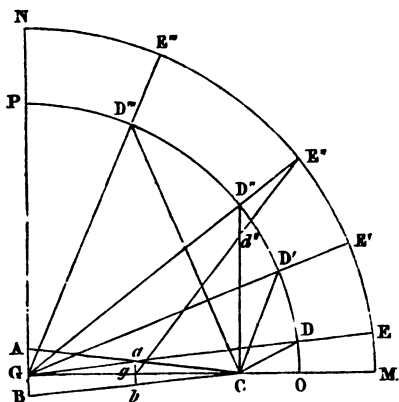


FIG. 27

is the middle point between the two eyes, the plane GMN being, as before, perpendicular to the plane passing through ACB . Now, as the distance of the eye from G is supposed to be the same, and as AB is invariable as well as the distance between the eyes, the distance of the binocular

centres o , D , D' , D'' , D''' , P from G , will also be invariable, and lie in a circle ODP , whose centre is G , and whose radius is GO , the point o being determined by the formula $GO = GD = \frac{GM \times AB}{AB + EL}$. Hence, in order to find the binocular centres D , D' , D'' , D''' , &c., at any altitude, E , E' , &c., we have only to join EG , $E'G$, &c., and the points of intersection D , D' , &c., will be the binocular centres, and the lines DC , $D'C$, &c., drawn to c , will be the real lengths and inclinations of the united images of the lines AC , BC .

When GO is greater than GC there is obviously some angle A , or $E'GM$, at which $D''C$ is perpendicular to GC .

This takes place when $\text{Cos. } A = \frac{GO}{GC}$. When o coincides with c , the images CD , CD' , &c., will have the same positions and magnitudes as the chords of the altitudes A of the eyes above the plane GC . In this case the raised or united images will just reach the perpendicular when the eye is in the plane GCM , for since $GC = GO$, $\text{Cos. } A = 1$ and $A = 0$.

When the eye at any position, E' for example, sees the points A and B united at D'' , it sees also the whole lines AC , BC forming the image $D''C$. The binocular centre must, therefore, run rapidly along the line $D''C$; that is, the inclination of the optic axes must gradually diminish till the binocular centre reaches c , when all strain is removed. The vision of the image $D''C$, however, is carried on so rapidly that the binocular centre returns to D'' without the eye being sensible of the removal and resumption of the strain which is required in maintaining a view of the united image $D''C$. If we now suppose AB to diminish, the binocular centre will advance towards G , and the length

and inclination of the united images DC, D'C, &c., will diminish also, and *vice versa*. If the distance BL (Fig. 26) between the eyes diminishes, the binocular centre will retire towards E, and the length and inclination of the images will increase. Hence persons with eyes more or less distant will see the united images in different places and of different sizes, though the quantities A and AB be invariable.

While the eyes at E' are running along the lines AC, BC, let us suppose them to rest upon the points ab equidistant from c. Join ab, and from the point g, where ab intersects GC, draw the line gE', and find the point d'' from the formula $gd'' = \frac{gE' \times ab}{ab + EL}$. Hence the two points a, b will be united at d'', and when the angle E'GC is such that the line joining D and c is perpendicular to GC, the line joining d''c will also be perpendicular to GC, the loci of the points D''d'', &c., will be in that perpendicular, and the image DC, seen by successive movements of the binocular centre from D'' to c, will be a straight line.

In the preceding observations we have supposed that the binocular centre D'', &c., is between the eye and the lines AC, BC; but the points A, c, and all the other points of these lines, may be united by fixing the binocular centre beyond AB. Let the eyes, for example, be at E'; then if we unite A, B when the eyes converge to a point, Δ'', (not seen in the Figure) beyond G, we shall have $G\Delta'' = \frac{GE' \times AB}{EL - AB}$; and if we join the point Δ'' thus found and c, the line Δ''c will be the united image of AC and BC, the binocular centre ranging from Δ'' to c, in order to see it as one line. In like manner, we may find the position and length of the

image $\Delta'''C$, $\Delta'C$, and ΔC , corresponding to the position of the eyes at $E''E$ and E . Hence all the united images of AC , BC , viz., $C\Delta'''$, $C\Delta''$, &c., will lie below the plane of ABC , and extend beyond a vertical line NG continued; and they will grow larger and larger, and approximate in direction to CG as the eyes descend from E'' to M . When the eyes are near to M , and a little above the plane of ABC , the line, when not carefully observed, will have the appearance of coinciding with CG , but stretching a great way beyond G . This extreme case represents the celebrated experiment with the compasses, described by Dr. Smith, and referred to by Professor Wheatstone. He took a pair of compasses, which may be represented by ACB , AB being their points, AC , BC their legs, and C their joint; and having placed his eyes about E , above their plane, he made the following experiment:—"Having opened the points of a pair of compasses somewhat wider than the interval of your eyes, with your arm extended, hold the head or joint in the ball of your hand, with the points outwards, and equidistant from your eyes, and somewhat higher than the joint. Then *fixing your eyes upon any remote object* lying in the plane that bisects the interval of the points, you will first perceive two pair of compasses, (each by being doubled with their inner legs crossing each other, not unlike the old shape of the letter *W*.) But by compressing the legs with your hand the two inner points will come nearer to each other; and when they unite (having stopped the compression) the two inner legs will also entirely coincide and bisect the angle under the outward ones, and will appear more vivid, thicker, and larger, than they do, so as to reach from your hand to the remotest object in view even

in the horizon itself, if the points be exactly coincident.”¹ Owing to his imperfect apprehension of the nature of this phenomenon, Dr. Smith has omitted to notice that the united legs of the compasses lie below the plane of $\triangle ABC$, and that they never can extend further than the binocular centre at which their points A and B are united.

There is another variation of these experiments which possesses some interest, in consequence of its extreme case having been made the basis of a new theory of visible direction, by the late Dr. Wells.² Let us suppose the eyes of the observer to advance from E to N , and to descend along the opposite quadrant on the left hand of NG , but not drawn in Fig. 27, then the united image of AC , BC will gradually descend towards CG , and become larger and larger. When the eyes are a very little above the plane of $\triangle ABC$, and so far to the left hand of AB that CA points nearly to the left eye and CB to the right eye, then we have the circumstances under which Dr. Wells made the following experiment :—“ If we hold two thin rules in such a manner that their sharp edges (AC , BC in Fig. 27) shall be in the optic axes, one in each, or rather a little below them, *the two edges will be seen united in the common axis*, (GC in Fig. 27 ;) and this apparent edge will seem of the same length with that of either of the real edges, when seen alone by the eye in the axis of which it is placed.” This experiment, it will be seen, is the same with that of Dr. Smith, with this difference only, that the points of the compasses are directed towards the eyes. Like Dr. Smith Dr. Wells has omitted to notice that the united image

¹ Smith's *Opticks*, vol. ii. p. 388, § 977.

² *Essay on Single Vision*, &c., p. 44.

risers above GH , and he commits the opposite error of Dr. Smith, in making the length of the united image too short.

If in this form of the experiment we fix the binocular centre beyond C , then the united images of AC , and BC descend below GC , and vary in their length, and in their inclination to GC , according to the height of the eye above the plane of ABC , and its distance from $A B$.

CHAPTER VII

DESCRIPTION OF DIFFERENT STEREOSCOPES.

ALTHOUGH the lenticular stereoscope has every advantage that such an instrument can possess, whether it is wanted for experiments on binocular vision—for assisting the artist by the reproduction of objects in relief, or for the purposes of amusement and instruction, yet there are other forms of it which have particular properties, and which may be constructed without the aid of the optician, and of materials within the reach of the humblest inquirers. The first of these is—

1. *The Tubular Reflecting Stereoscope.*

In this form of the instrument, shewn in Fig. 28, the pictures are seen by reflexion from two specula or prisms placed at an angle of 90° , as in Mr. Wheatstone's instrument. In other respects the two instruments are essentially different.

In Mr. Wheatstone's stereoscope he employs two mirrors, each *four inches* square—that is, he employs *thirty-two* square inches of reflecting surface, and is therefore under the necessity of employing glass mirrors, and making a clumsy, unmanageable, and unscientific instrument, with all the imperfections which we have pointed out in a preceding chapter. It is not easy to understand why mirrors of such

a size should have been adopted. The reason of their being made of common looking-glass is, that metallic or prismatic reflectors of such a size would have been extremely expensive.

It is obvious, however, from the slightest consideration, that reflectors of such a size are wholly unnecessary, and that *one square* inch of reflecting surface, in place of *thirty-two*, is quite sufficient for uniting the binocular pictures. We can, therefore, at a price as low as that of the 4-inch glass reflectors, use mirrors of speculum metal, steel, or even silver, or rectangular glass prisms, in which the images are obtained by total reflexion. In this way the stereoscope becomes a real optical instrument, in which the reflexion is made from surfaces single and perfectly flat, as in the second reflexion of the Newtonian telescope and the microscope of Amici, in which pieces of looking-glass were never used. By thus diminishing the reflectors, we obtain a portable tubular instrument occupying nearly as little room as the lenticular stereoscope, as will be seen from Fig. 28, where ABCD is

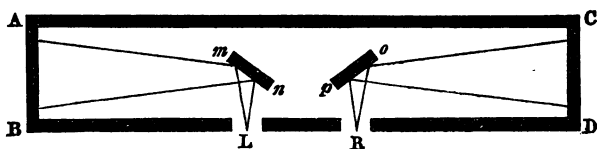


FIG. 28.

a tube whose diameter is equal to the largest size of one of the binocular pictures which we propose to use, the left-eye picture being placed at CD, and the right-eye one at AB. If they are transparent, they will be illuminated through paper or ground glass, and if opaque, through openings in the tube. The image of AB, reflected to the left eye L from the small mirror *mn*, and that of CD to the right eye R

from the mirror *op*, will be united exactly as in Mr. Wheatstone's instrument already described. The distance of the two ends, *n*, *p*, of the mirrors should be a little greater than the smallest distance between the two eyes. If we wish to magnify the picture, we may use two lenses, or substitute for the reflectors a totally reflecting glass prism, in which one or two of its surfaces are made convex.¹

2. *The Single Reflecting Stereoscope.*

This very simple instrument, which, however, answers only for symmetrical figures, such as those shewn at A and B, which must be either two right-eye or two left-eye pictures, is shewn in Fig. 29. A single reflector, MN, which

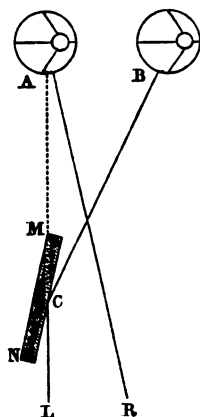


FIG. 29.

may be either a piece of glass, or a piece of mirror-glass, or a small metallic speculum, or a rectangular prism, is placed

¹ We may use also the lens prism, which I proposed many years ago in the *Edinburgh Philosophical Journal*.

at *MN*. If we look into it with the left eye *L*, we see, by reflexion from its surface at *C*, a reverted image, or a right-eye picture of the left-eye picture *B*, which, when seen in the direction *LCA*, and combined with the figure *A*, seen directly with the right eye *R*, produces a *raised* cone; but if we turn the reflector *L* round, so that the right eye may look into it, and combine a reverted image of *A*, with the figure *B* seen directly with the left eye *L*, we shall see a *hollow* cone. As $BC + CL$ is greater than EA , the reflected image will be slightly less in size than the image seen directly, but the difference is not such as to produce any perceptible effect upon the appearance of the hollow or the raised cone. By bringing the picture viewed by reflexion a little nearer the reflector *MN*, the two pictures may be made to have the same apparent magnitude.

If we substitute for the single reflector *MN*, two reflectors such as are shewn at *M*, *N*, Fig. 30, or a prism *P*, which

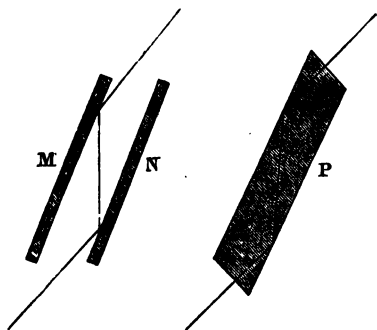


FIG. 30.

gives two internal reflexions, we shall have a general stereoscope, which answers for landscapes and portraits.

The reflectors M , N or P may be fitted up in a conical tube, which has an elliptical section to accommodate two figures at its farther end, the major axis of the ellipse being parallel to the line joining the two eyes.

3. *The Double Reflecting Stereoscope.*

This instrument differs from the preceding in having a single reflector, MN , $M'N'$, for each eye, as shewn in Fig. 31,

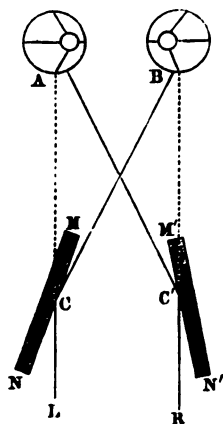


FIG. 31.

and the effect of this is to exhibit, *at the same time, the raised and the hollow cone*. The image of B , seen by reflexion from MN at the point C , is combined with the picture of A , seen directly by the *right* eye B , and forms a *hollow* cone; while the image of A , seen by reflexion from $M'N'$ at the point C' , is combined with the picture of B , seen directly by the *left* eye L , and forms a *raised* cone.

Another form of the double reflecting stereoscope is shewn in Fig. 32, which differs from that shewn in Fig. 31 in,

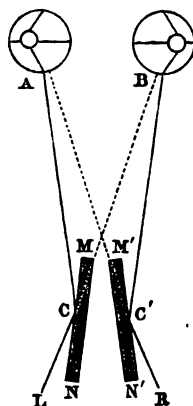


FIG. 32.

the position of the two reflectors and of the figures to be united. The reflecting faces of the mirrors are turned outwards, their distance being less than the distance between the eyes, and the effect of this is to exhibit at the same time the *raised* and the *hollow* cone, the hollow cone being now on the right-hand side.

If in place of two right or two left eye pictures, as shewn in Figs. 29, 31, and 32, we use one right eye and one left eye picture, and combine the reflected image of the one with the reflected image of the other, we shall have a *raised* cone with the stereoscope, shewn in Fig. 31, and a *hollow* cone with the one in Fig. 32.

The double reflecting stereoscope, in both its forms, is a general instrument for portraits and landscapes, and thus possesses properties peculiar to itself.

The reflectors may be glass or metallic specula, or total reflexion prisms.

4. *The Total Reflexion Stereoscope.*

This form of the stereoscope is a very interesting one, and possesses valuable properties. It requires only a small prism and *one* diagram, or picture of the solid, as seen by one eye; the other diagram, or picture which is to be combined with it, being created by total reflexion from the base of the prism. This instrument is shewn in Fig. 33,

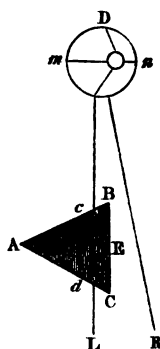


FIG. 33.

where D is the picture of a cone as seen by the left eye L, and ABC a prism, whose base BC is so large, that when the eye is placed close to it, it may see, by reflexion, the whole of the diagram D. The angles ABC, ACB must be equal, but may be of any magnitude. Great accuracy in the equality of the angles is not necessary; and a prism constructed, by a lapidary, out of a fragment of thick plate-

glass, the face BC being one of the surfaces of the plate, will answer the purpose. When the prism is placed at α , Fig. 34, at one end of a conical tube LD , and the diagram



FIG. 34.

D at the other end, in a cap, which can be turned round so as to have the line mn , Fig. 33, which passes through the centre of the base and summit of the cone parallel to the line joining the two eyes, the instrument is ready for use. The observer places his left eye at L , and views with it the picture D , as seen by total reflexion from the base BC of the prism, Figs. 33 and 35, while with his right eye R , Fig. 33, he views the real picture directly. The first of these pictures being the reverse of the second D , like all pictures formed by one reflexion, we thus combine

two dissimilar pictures into a *raised* cone, as in the figure, or into a *hollow* one, if the picture at D is turned round 180° . If we place the images of two diagrams, one like one of those at A, Fig. 31, and the other like the one at B, vertically above one another, we shall then see, at the same time, the *raised* and the *hollow* cone, as produced in the lenticular stereoscope by the three diagrams, two like those in Fig. 31, and a third like the one at A. When the prism is good, the dissimilar image, produced by the two refractions at B and C, and the one reflexion at E, is, of course, more accurate than if it had been drawn by the most skilful artist; and therefore this form of the stereoscope has in this respect an advantage over every other in which two dissimilar figures, executed by art, are necessary. In consequence of the length of the reflected pencil $DB + BE + EC + CL$ being a little greater than the direct pencil of rays DE , the two images combined have not exactly the same apparent magnitude; but the difference is not perceptible to the eye, and a remedy could easily be provided were it required.

If the conical tube LD is held in the left hand, the left eye must be used, and if in the right hand the right eye must be used, so that the hand may not obstruct the direct vision of the drawing by the eye which does not look through the prism. The cone LD must be turned round slightly in the hand till the line mn joining the centre and apex of the figure is parallel to the line joining the two eyes. The same line must be parallel to the plane of reflexion from the prism; but this parallelism is secured by fixing the prism and the drawing.

It is scarcely necessary to state that this stereoscope is

applicable only to those diagrams and forms where the one image is the reflected picture of the other.

If we wish to make a microscopic stereoscope of this form, or to magnify the drawings, we have only to cement plano-convex lenses, of the requisite focal length, upon the faces AB , AC of the prism, or, what is simpler still, to use a section of a deeply convex lens ABC , Fig. 35, and apply

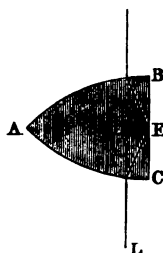


FIG. 35.

the other half of the lens to the right eye, the face BC having been previously ground flat and polished for the prismatic lens. By using a lens of larger focus for the right eye, we may correct, if required, the imperfection arising from the difference of paths in the reflected and direct pencils. This difference, though trivial, might be corrected, if thought necessary, by applying to the right eye the central portion of the same lens whose margin is used for the prism.

If we take the drawing of a six-sided pyramid as seen by the right eye, as shewn in Fig. 36, and place it in the total-reflexion stereoscope at D , Fig. 33, so that the line MN coincides with mn , and is parallel to the line joining the eyes of the observer, we shall perceive a perfect raised

pyramid of a given height, the reflected image of CD , Fig. 36, being combined with AF , seen directly. If we now turn the figure round 30° , CD will come into the position AB , and unite with AB , and we shall still perceive a raised pyramid, with less height and less symmetry. If we turn it round 30° more, CD will be combined with BC ,

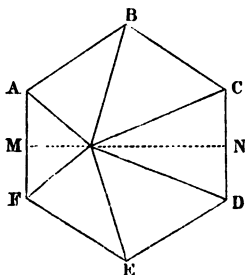


FIG. 36.

and we shall still perceive a raised pyramid with still less height and still less symmetry. When the figure is turned round other 30° , or 90° degrees from its first position, CD will coincide with CD seen directly, and the combined figures will be perfectly flat. If we continue the rotation through other 30° , CD will coincide with DE , and a slightly hollow, but not very symmetrical figure, will be seen. A rotation of other 30° will bring CD into coalescence with EF , and we shall see a still more hollow and more symmetrical pyramid. A further rotation of other 30° , making 180° from the commencement, will bring CD into union with AF ; and we shall have a perfectly symmetrical hollow pyramid of still greater depth, and the exact counterpart of the raised pyramid which was

seen before the rotation of the figure commenced. If the pyramid had been square, the *raised* would have passed into the *hollow* pyramid by rotations of 45° each. If it had been rectangular, the change would have been effected by rotations of 90° . If the space between the two circular sections of the cone in Fig. 31 had been uniformly shaded, or if lines had been drawn from every degree of the one circle to every corresponding degree in the other, in place of from every 90th degree, as in the Figure, the raised cone would have gradually diminished in height, by the rotation of the figure, till it became flat, after a rotation of 90° ; and by continuing the rotation it would have become hollow, and gradually reached its maximum depth after a revolution of 180° .

5. *The Single-Prism Stereoscope.*

Although the idea of uniting the binocular pictures by a single prism applied to one eye, and refracting one of the pictures so as to place it upon the other seen directly by the other eye, or by a prism applied to each eye, could hardly have escaped the notice of any person studying the subject, yet the experiment was, so far as I know, first made and published by myself. I found two prisms quite unnecessary, and therefore abandoned the use of them, for reasons which will be readily appreciated. This simple instrument is shewn in Fig. 37, where A, B are the dissimilar pictures, and P a prism with such a refracting angle as is sufficient to lay the image of A upon B, as seen by the right eye. If we place a *second* prism before the eye R, we require it only to have half the refracting angle of the prism P, because each prism now refracts

the picture opposite to it only half way between A and B, where they are united. This, at first sight, appears to be an advantage, for as there must always be a certain degree

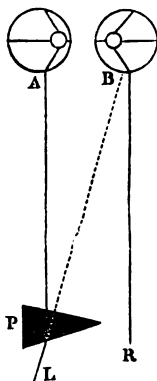


FIG. 37.

of colour produced by a single prism, the use of two prisms, with half the refracting angle, might be supposed to reduce the colour one-half. But while the colour produced by each prism is thus reduced, the colour over the whole picture is the same. Each luminous edge with two prisms has both red and blue tints, whereas with one prism each luminous edge has only one colour, either red or blue. If the picture is very luminous these colours will be seen, but in many of the finest opaque pictures it is hardly visible. In order, however, to diminish it, the prism should be made of glass with the lowest dispersive power, or with rock crystal. A single plane surface, ground and polished by a lapidary, upon the edge of a piece of plate glass, a little

larger than the pupil of the eye, will give a prism sufficient for every ordinary purpose. Any person may make one in a few minutes for himself, by placing a little bit of good window glass upon another piece inclined to it at the proper angle, and inserting in the angle a drop of fluid. Such a prism will scarcely produce any perceptible colour.

If a single-prism reflector is to be made perfect, we have only to make it achromatic, which could be done *extempore*, by correcting the colour of the fluid prism by another fluid prism of different refractive and dispersive power.

With a good achromatic prism the single-prism stereoscope is a very fine instrument; and no advantage of any value could be gained by using *two achromatic prisms*. In the article on New Stereoscopes, published in the Transactions of the Royal Society of Arts for 1849, and in the Philosophical Magazine for 1852, I have stated in a note that *I believed* that Mr. Wheatstone had used *two achromatic prisms*. This, however, was a mistake, as already explained,¹ for such an instrument was never made, and has never been named in any work previous to 1849, when it was mentioned by myself in the note above referred to.

If we make a double prism, or join two, as shewn at P, P' in Fig. 38, and apply it to two dissimilar figures A, B, one of which is the reflected image of the other, so that with the left eye L and the prism P we place the refracted image of A upon B, as seen by the right eye R, we shall see a *raised* cone, and if with the prism P' we place

¹ See Chap. I. pp. 33-36.

the image of B upon A we shall see a *hollow* cone. If we place the left eye L at O, behind the common base of the

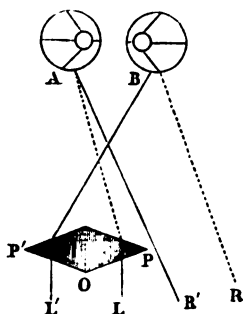


FIG. 38.

prism, we shall see with one-half of the pupil the *hollow* cone and with the other half the *raised* cone.

6. The Opera-Glass Stereoscope.

As the eyes themselves form a stereoscope to those who have the power of quickly converging their axes to points nearer than the object which they contemplate, it might have been expected that the first attempt to make a stereoscope for those who do not possess such a power, would have been to supply them with auxiliary eyeballs capable of combining binocular pictures of different sizes at different distances from the eye. This, however, has not been the case, and the stereoscope for this purpose, which we are about to describe, is one of the latest of its forms.

In Fig. 39, MN is a small inverting telescope, consisting of two convex lenses M, N, placed at the sum of their focal

distances, and of another of the same kind. When the two eyes, R, L, look through the two telescopes directly at the dissimilar pictures A, B, they will see them with perfect

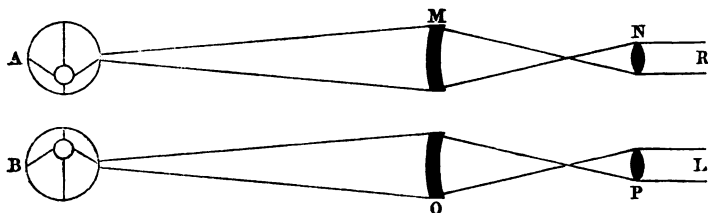


FIG. 39.

distinctness ; but, by the slightest inclination of the axes of the telescopes, the two images can be combined, and the stereoscopic effect immediately produced. With the dissimilar pictures in the diagram a *hollow* cone is produced ;

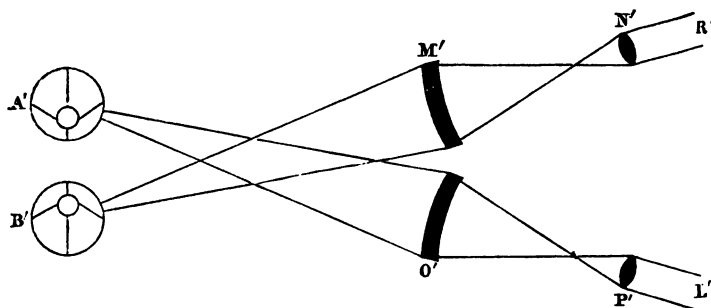


FIG. 40.

but if we look at B with the telescope M'N', as in Fig. 40, and at A' with O'P', a *raised* cone will be seen. With the usual binocular slides containing portraits or landscapes, the

pictures are seen in relief by combining the right-eye one with the left-eye one.

The instrument now described is nothing more than a double opera-glass, which itself forms a good stereoscope. Owing, however, to the use of a concave eye-glass, the field of view is very small, and therefore a convex glass, which gives a larger field, is greatly to be preferred.

The little telescopes, *MN*, *OP*, may be made one and a half or even one inch long, and fitted up, either at a fixed or with a variable inclination, in a pyramidal box, like the lenticular stereoscope, and made equally portable. One of these instruments was made for me some years ago by Messrs. Horne and Thornthwaite, and I have described it in the *North British Review*¹ as having the properties of a *Binocular Cameoscope*, and of what has been absurdly called a *Pseudoscope*, seeing that every inverting eye-piece and every stereoscope is entitled to the very same name.

The little telescope may be made of one piece of glass, *convex* at each end, or *concave* at the eye-end if a small field is not objectionable,—the length of the piece of glass, in the *first* case, being equal to the *sum*, and, in the *second* case, to the *difference* of the focal lengths of the virtual lenses at each end.²

7. *The Eye-Glass Stereoscope.*

As it is impossible to obtain, by the ocular stereoscope, pictures in relief from the beautiful binocular slides which are made in every part of the world for the lenticular stereo-

¹ For 1852, vol. xvii. p. 200.

² These solid telescopes may be made achromatic by cementing concave lenses of flint glass upon each end, or of crown glass if they are made of flint glass.

scope, it is very desirable to have a portable stereoscope which can be carried safely in our purse, for the purpose of examining stereoscopically all such binocular pictures.

If placed together with their plane sides in contact, a plano-convex lens, *AB*, and a plano-concave one, *CD*, of the same glass and the same focal length, will resemble a thick watch-glass, and on looking through them, we shall see objects of their natural size and in their proper place; but if we slip the concave lens, *CD*, to a side, as shewn in Fig. 41,



FIG. 41.

we merely displace the image of the object which we view, and the displacement increases till the centre of the concave lens comes to the margin of the convex one. We thus obtain a variable prism, by means of which we can, with the left eye, displace one of the binocular pictures, and lay it upon the other, as seen by the right eye. We may use semi-lenses or quarters of lenses, and we may make them achromatic or nearly so if we desire it. Double convex and double concave lenses may also be used, and the motion of the concave one regulated by a screw. In one which I constantly use, the concave lens slides in a groove over a convex quarter lens.

By employing two of these variable prisms, we have an *Universal Stereoscope* for uniting pictures of various sizes and at various distances from each other, and the prisms may be placed in a pyramidal box, like the lenticular stereoscope.

8. *The Reading-Glass Stereoscope.*

If we take a reading-glass whose diameter is not less than two inches and three quarters, and look through it with both eyes at a binocular picture in which the right-eye view is on the left hand, and the left-eye view on the right hand, as in the ocular stereoscope, we shall see each picture doubled, and the degree of separation is proportional to the distance of the picture from the eye. If the distance of the binocular pictures from each other is small, the two middle images of the four will be united when their distance from the lens is not very much greater than its focal length. With a reading-glass $4\frac{1}{2}$ inches in diameter, with a focal length of two feet, binocular pictures, in which the distance of similar parts is *nine* inches, are united without any exertion of the eyes at the distance of eight feet. With the same reading-glass, binocular pictures, at the usual distance of $2\frac{1}{2}$ inches, will be united at the distance of $2\frac{1}{2}$ or even $2\frac{1}{2}$ feet. If we advance the reading-glass when the distance is 2 or 3 feet, the picture in relief will be magnified, but, though the observer may not notice it, the separated images are now kept united by a slight convergency of the optic axes. Although the pictures are placed so far beyond the anterior focus of the lens, they are exceedingly distinct. The distinctness of vision is sufficient, at least to long-sighted eyes, when the pictures are placed within 16 or 18 inches of the observer, that is, 6 or 8 inches nearer the eye than the anterior focus of the lens. In this case we can maintain the union of the pictures only when we begin to view them at a distance of $2\frac{1}{2}$ or 3 feet, and then gradually advance the lens within 16 or 18 inches of the pictures.

At considerable distances, the pictures are most magnified by advancing the lens while the head of the observer is stationary.

9. *The Camera Stereoscope.*

The object of this instrument is to unite the transient pictures of groups of persons or landscapes, as delineated in two dissimilar pictures, on the ground glass of a binocular camera. If we attach to the back of the camera a lenticular stereoscope, so that the two pictures on the ground glass occupy the same place as its usual binocular slides, we shall see the group of figures in relief under every change of attitude, position, and expression. The two pictures may be formed in the air, or, more curiously still, upon a wreath of smoke. As the figures are necessarily inverted in the camera, they will remain inverted by the lenticular and every other instrument but the opera-glass stereoscope, which inverts the object. By applying it therefore to the camera, we obtain an instrument by which the photographic artist can make experiments, and try the effect which will be produced by his pictures before he takes them. He can thus select the best forms of groups of persons and of landscapes, and thus produce works of great interest and value.

10. *The Chromatic Stereoscope.*

The chromatic stereoscope is a form of the instrument in which relief or apparent solidity is given to a single figure with different colours delineated upon a plane surface.

If we look with both eyes through a lens L L, Fig. 42, about $2\frac{1}{2}$ inches in diameter or upwards, at any object having

colours of different degrees of refrangibility, such as the coloured boundary lines on a map, a red rose among green leaves and on a blue background, or any scarlet object what-

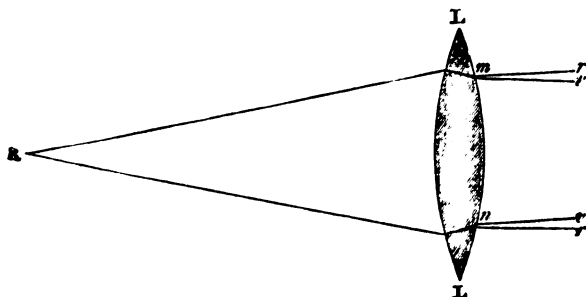


FIG. 42.

ever upon a violet ground, or in general any two simple colours not of the same degree of refrangibility, *the differently coloured parts of the object will appear at different distances from the observer.*

Let us suppose the rays to be *red* and *violet*, those which differ most in refrangibility. If the red rays radiate from the anterior focus R, or red rays of the lens L L, they will emerge parallel, and enter the eye at *m*; but the violet rays radiating from the same focus, being more refrangible, will emerge in a state of convergence, as shewn at *m'*, *n'*, the red rays being *mr*, *nr*. The part of the object, therefore, from which the red rays come, will appear nearer to the observer than the parts from which the violet rays come, and if there are other colours or rays of intermediate refrangibilities, they will appear to come from intermediate distances.

If we place a small *red* and *violet* disc, like the smallest wafer, beside one another, so that the line joining their centres is perpendicular to the line joining the eyes, and suppose that rays from both enter the eyes with their optical axes parallel, it is obvious that the distance between the violet images on each retina will be *less* than the distance between the *red* images, and consequently the eyes will require to converge their axes to a *nearer* point in order to unite the red images, than in order to unite the violet images. The red images will therefore appear at this nearer point of convergence, just as, in the lenticular stereoscope, the more distant pair of points in the dissimilar images appear when united nearer to the eye. By the two eyes alone, therefore, we obtain a certain, though a small degree of relief from colours. With the lens LL, however, the effect is greatly increased, and we have the *sum* of the *two* effects.

From these observations, it is manifest that the reverse effect must be produced by a concave lens, or by the common stereoscope, when *two* coloured objects are employed or united. The *blue* part of the object will be seen *nearer* the observer, and the red part of it more *remote*. It is, however, a curious fact, and one which appeared difficult to explain, that in the stereoscope the colour-relief was not brought out as might have been expected. Sometimes the red was nearest the eye, and sometimes the blue, and sometimes the object appeared without any relief. The cause of this is, that the colour-relief given by the common stereoscope was the opposite of that given by the eye, and it was only the *difference* of these effects that ought to have been observed; and though the influence of the eyes was an

inferior one, it often acted alone, and sometimes ceased to act at all, in virtue of that property of vision by which we see only with one eye when we are looking with two.

In the chromatic stereoscope, Fig. 42, the intermediate part *mn* of the lens is of no use, so that out of the margin of a lens upwards of $2\frac{1}{2}$ inches in diameter, we may cut a dozen of portions capable of making as many instruments. These portions, however, a little larger only than the pupil of the eye, must be placed in the same position as in Fig. 42.

All the effects which we have described are greatly increased by using lenses of highly-dispersing flint glass, oil of cassia, and other fluids of a great dispersive power, and avoiding the use of compound colours in the objects placed in the stereoscope.

It is an obvious result of these observations, that in painting, and in coloured decorations of all kinds, the *red* or less refrangible colours should be given to the prominent parts of the object to be represented, and the *blue* or more refrangible colours to the background and the parts of the objects that are to retire from the eye.

11. *The Microscope Stereoscope.*

The lenticular form of the stereoscope is admirably fitted for its application to small and microscopic objects. The first instruments of this kind were constructed by myself with quarter-inch lenses, and were 3 inches long and only 1 and $1\frac{1}{2}$ deep.¹ They may be carried in the pocket, and exhibit all the properties of the instrument to the greatest advantage. The mode of constructing and using the instrument is precisely the same as in the common stereoscope ;

¹ *Phil. Mag.*, Jan. 1852, vol. III. p. 19.

but in taking the dissimilar pictures, we must use either a small binocular camera, which will give considerably magnified representations of the objects, or we must procure them from the compound microscope. The pictures may be obtained with a small single camera, by first taking one picture, and then shifting the object in the focus of the lens, through a space corresponding with the binocular angle. To find this space, which we may call x , make d the distance of the object from the lens, n the number of times it is to be magnified, or the distance of the image behind the lens, and D the distance of the eyes; then we shall have

$$nd : d = D : x, \text{ and } x = \frac{D}{n},$$

that is, the space is equal to the distance between the eyes divided by the magnifying power.

With the binocular microscope of Professor Riddell,¹ and the same instrument as improved by M. Nachet, binocular pictures are obtained directly by having them drawn, as Professor Riddell suggests, by the camera lucida, but it would be preferable to take them photographically.

Portraits for locketts or rings might be put into a very small stereoscope, by folding the one lens back upon the other.

¹ *American Journal of Science*, 1852, vol. xv. p. 68.

CHAPTER VIII.

METHOD OF TAKING PICTURES FOR THE STEREOSCOPE.

HOWEVER perfect be the stereoscope which we employ, the effect which it produces depends upon the accuracy with which the binocular pictures are prepared. The pictures required for the stereoscope may be arranged in four classes :—

1. The representations of geometrical solids as seen with two eyes.
2. Portraits, or groups of portraits, taken from living persons or animals.
3. Landscapes, buildings, and machines or instruments.
4. Solids of all kinds, the productions of nature or of art.

Geometrical Solids.

Representations of geometrical solids, were, as we have already seen, the only objects which for many years were employed in the reflecting stereoscope. The figures thus used are so well known that it is unnecessary to devote much space to their consideration. For ordinary purposes they may be drawn by the hand, and composed of squares, rectangles, and circles, representing quadrangular pyramids, truncated, or terminating in a point, cones, pyramids with polygonal bases, or more complex forms in which raised

Let L, R, Fig. 43, be the left and right eye, and A the middle point between them. Let MN be the plane on

which an object or solid whose height is CB is to be drawn. Through B draw LB , meeting MN in c ; then if the object is a solid, with its apex at B , cc will be the distance of its apex from the centre c of its base, as seen by the left eye. When seen by the right eye R , cc' will be its distance, c' lying on the left side of c . Hence if the figure is a cone, the dissimilar pictures of it will be two circles, in one of which its apex is placed at the distance cc from its centre, and in the other at the distance cc' on the other side of the centre. When these two plane figures are placed in the stereoscope, they will, when combined, represent a raised cone when the points c, c' are nearer one another than the centres of the circles representing the cone's base, and a *hollow* cone when the figures are interchanged.

If we call E the distance between the two eyes, and h the height of the solid, we shall have $AB : h = \frac{E}{2} : cc$, and $cc = \frac{hE}{2AB}$, or $\frac{5h}{4AB}$, which will give us the results in the following table, E being $2\frac{1}{2}$, and AO 8 inches :—

Height of object.

 $BC = h$ $AB = AO - h$ cc

Inches.

1

7

0.179

2

6

0.4166

3

5

0.75

4

4

1.25

5

3

2.083

6

2

3.75

7

1

8.75

8

0

Infinite.

If we now converge the optic axes to a point b , and wish to ascertain the value of cc , which will give dif-

ferent depths, d , of the *hollow* solids corresponding to different values of cb , we shall have $ab : \frac{R}{2} = d : cc'$, and $cc' = \frac{dR}{2AB}$, which, making $AC = 8$ inches, as before, will give the following results :—

Depth.		
$cb = d$	$ab = AC + d$	cc' Inches.
1	9	0.139
2	10	0.25
3	11	0.34
4	12	0.4166
5	13	0.48
6	14	0.535
7	15	0.58
8	16	0.625
9	17	0.663
10	18	0.696
11	19	0.723
12	20	0.75

The values of h and d when cc , cc' are known, will be found from the formulæ $h = \frac{2AB \cdot cc}{R}$, and $d = \frac{2AB \cdot cc'}{R}$. As cc is always equal to cc' in each pair of figures or dissimilar pictures, the depth of the *hollow* cone will always appear much greater than the height of the raised one. When $cc = cc' = 0.75$, $h : d = 3 : 12$. When $cc = cc' = 0.4166$, $h : d = 2 : 4$, and when $cc = cc' = 0.139$, $h : d = 0.8 : 1.0$.

When the solids of which we wish to have binocular pictures are symmetrical, the one picture is the reflected image of the other, or its reverse, so that when we have drawn the solid as seen by one eye, we may obtain the other

by copying its reflected image, or by simply taking a copy of it as seen through the paper.

When the geometrical solids are not symmetrical, their dissimilar pictures must be taken photographically from models, in the same manner as the dissimilar pictures of other solids.

Portraits of Living Persons or Animals.

Although it is possible for a clever artist to take two portraits, the one as seen by his right, and the other as seen by his left eye, yet, owing to the impossibility of fixing the sitter, it would be a very difficult task. A bust or statue would be more easily taken by fixing two apertures $2\frac{1}{2}$ inches distant, as the two points of sight, but even in this case the result would be imperfect. The photographic camera is the only means by which living persons and statues can be represented by means of two plane pictures to be combined by the stereoscope; and but for the art of photography, this instrument would have had a very limited application.

It is generally supposed that photographic pictures, whether in Daguerreotype or Talbotype, are accurate representations of the human face and form, when the sitter sits steadily, and the artist knows the resources of his art. *Quis solem esse falsum dicere audeat?* says the photographer, in rapture with his art. *Solem esse falsum dicere audeo*, replies the man of science, in reference to the hideous representations of humanity which proceed from the studio of the photographer. The sun never errs in the part which he has to perform. The sitter may sometimes contribute his share to the hideousness of his portrait by involuntary nervous motion, but it is upon the artist or his art that the blame must be laid.

If the single portrait of an individual is a misrepresentation of his form and expression, the combination of two such pictures into a solid must be more hideous still, not merely because the error in form and expression is retained or doubled, but because the source of error in the single portrait is incompatible with the application of the stereoscopic principle in giving relief to the plane pictures. The art of stereoscopic portraiture is in its infancy, and we shall therefore devote some space to the development of its true principles and practice.

In treating of the images of objects formed by lenses and mirrors with spherical surfaces, optical writers have satisfied themselves by shewing that the images of straight lines so formed are conic sections, elliptical, parabolic, or hyperbolic. I am not aware that any writer has treated of the images of solid bodies, and of their shape as affected by the size of the lenses or mirrors by which they are formed, or has even attempted to shew how a perfect image of any object can be obtained. We shall endeavour to supply this defect.

In a previous chapter we have explained the manner in which images are formed by a small aperture, H , in the side, MN , of a camera, or in the window-shutter of a dark room. The rectangles br , $b'r'$, and $b''r''$, are images of the object BB , according as they are received at the same distance from the lens as the object, or at a less or a greater distance, the size of the image being to that of the object as their respective distances from the hole H . Pictures thus taken are accurate representations of the object, whether it be lineal, superficial, or solid, as seen from or through the hole H ; and if we could throw sufficient light upon the object, or make the material which receives the image very sensi-

tive, we should require no other camera for giving us photographs of all sizes. The only source of error which we can conceive, is that which may arise from the inflexion of light,

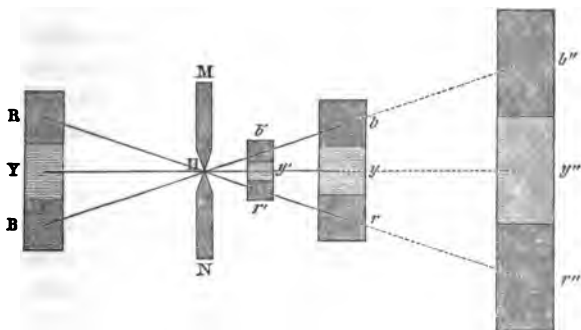


FIG. 44.

but we believe that it would exercise a small influence, if any, and it is only by experiment that its effect can be ascertained.

The Rev. Mr. Egerton and I have obtained photographs of a bust, in the course of ten minutes, with a very faint sun, and through an aperture less than the hundredth of an inch ; and I have no doubt that when chemistry has furnished us with a material more sensitive to light, a camera without lenses, and with only a pin-hole, will be the favourite instrument of the photographer. At present, no sitter could preserve his composure and expression during the number of minutes which are required to complete the picture.

But though we cannot use this theoretical camera, we may make some approximation to it. If we make the hole H a quarter of an inch, the pictures *br*, &c., will be faint and indistinct ; but by placing a thin lens a quarter of an

inch in diameter in the hole H, the distinctness of the picture will be restored, and, from the introduction of so much light, the photograph may be completed in a sufficiently short time. The lens should be made of rock crystal, which has a small dispersive power, and the ratio of curvature of its surfaces should be as six to one, the flattest side being turned to the picture. In this way there will be very little colour and spherical aberration, and no error produced by any striæ or want of homogeneity in the glass.

As the hole H is nearly the same as the greatest opening of the pupil, the picture which is formed by the enclosed lens will be almost identical with the one we see in monocular vision, which is always the most perfect representation of figures in relief.

With this approximately perfect camera, let us now compare the expensive and magnificent instruments with which the photographer practises his art. We shall suppose his camera to have its lens or lenses with an aperture of only *three* inches, as shewn at L R in Fig. 45. If we cover the whole

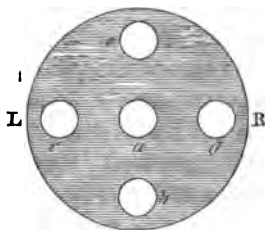


FIG. 45.

lens, or reduce its aperture to a quarter of an inch, as shewn at *a*, we shall have a correct picture of the sitter. Let us now take other *four* pictures of the same person, by re-

moving the aperture successively to b , c , d , and e : It is obvious that these pictures will all differ very perceptibly from each other. In the picture obtained through d , we shall see parts on the left side of the head which are not seen in the picture through c , and in the one through c , parts on the right side of the head not seen through d . In short, the pictures obtained through c and d are accurate dissimilar pictures, such as we have in binocular vision, (the distance cd being $2\frac{1}{2}$ inches,) and fitted for the stereoscope. In like manner, the pictures through b and e will be different from the preceding, and different from one another. In the one through b , we shall see parts *below* the eyebrows, below the nose, below the upper lip, and below the chin, which are not visible in the picture through e , nor in those through c and d ; while in the picture through e , we shall see parts above the brow, and above the upper lip, &c., which are not seen in the pictures through b , c , and d . In whatever part of the lens, *L.R.*, we place the aperture, we obtain a picture different from that through any other part, and therefore it follows, *that with a lens whose aperture is three inches, the photographic picture is a combination of about one hundred and thirty dissimilar pictures of the sitter, the similar parts of which are not coincident; or to express it in the language of perspective, the picture is a combination of about one hundred and thirty pictures of the sitter, taken from one hundred and thirty different points of sight!* If such is the picture formed by a *three-inch* lens, what must be the amount of the *anamorphism*, or distortion of form, which is produced by photographic lenses of diameters from *three* to *twelve* inches, actually used in photography? ¹

¹ See my *Treatise on Optics*, 2d edit., chap. vii. p. 65.

But it is not merely by the size of the lenses that hideous portraits are produced. In cameras with two achromatic lenses, the rays which form the picture pass through a large thickness of glass, which may not be altogether homogeneous,—through *eight* surfaces which may not be truly spherical, and which certainly scatter light in all directions,—and through an optical combination in which straight lines in the object must be conic sections in the picture !

Photography, therefore, cannot even approximate to perfection till the artist works with a camera furnished with a single quarter of an inch lens of rock crystal, having its radii of curvature as six to one, or what experience may find better, with an achromatic lens of the same aperture. And we may state with equal confidence, that the photographer who has the sagacity to perceive the defects of his instruments, the honesty to avow it, and the skill to remedy them by the applications of modern science, will take a place as high in photographic portraiture as a Reynolds or a Lawrence in the sister art.

Such being the nature of single portraits, we may form some notion of the effect produced by combining dissimilar ones in the stereoscope, so as to represent the original in relief. The single pictures themselves, including binocular and multocular representations of the individual, must, when combined, exhibit a very imperfect portrait in relief,—so imperfect, indeed, that the artist is obliged to take his two pictures from points of sight different from the correct points, in order to produce the least disagreeable result. This will appear after we have explained the correct method of taking binocular portraits for the stereoscope.

No person but a painter, or one who has the eye and the

taste of a painter, is qualified to be a photographer either in single or binocular portraiture. The first step in taking a portrait or copying a statue, is to ascertain in what aspect and at what distance from the eye it ought to be taken.

In order to understand this subject, we shall first consider the vision, with *one eye*, of objects of three dimensions, when of different magnitudes and placed at different distances. When we thus view a building, or a full-length or colossal statue, at a short distance, a picture of all its visible parts is formed on the retina. If we view it at a greater distance, certain parts cease to be seen, and other parts come into view ; and this change in the picture will go on, but will become less and less perceptible as we retire from the original. If we now look at the building or statue from a distance through a telescope, so as to present it to us with the same distinctness, and of the same apparent magnitude as we saw it at our first position, the two pictures will be essentially different ; all the parts which ceased to be visible as we retired will still be invisible, and all the parts which were not seen at our first position, but became visible by retiring, will be seen in the telescopic picture. Hence the parts seen by the near eye, and not by the distant telescope, will be those towards the middle of the building or statue, whose surfaces converge, as it were, towards the eye ; while those seen by the telescope, and not by the eye, will be the external parts of the object, whose surfaces converge less, or approach to parallelism. It will depend on the nature of the building or the statue which of these pictures gives us the most favourable representation of it.

If we now suppose the building or statue to be reduced

in the most perfect manner,—to half its size, for example,—then it is obvious that these two perfectly similar solids will afford a different picture, whether viewed by the eye or by the telescope. In the reduced copy, the inner surfaces visible in the original will disappear, and the outer surfaces become visible ; and, as formerly, it will depend on the nature of the building or the statue whether the reduced or the original copy gives the best picture.

If we repeat the preceding experiments with *two eyes* in place of *one*, the building or statue will have a different appearance ; surfaces and parts, formerly invisible, will become visible, and the body will be better seen because we see more of it ; but then the parts thus brought into view being seen, generally speaking, with one eye, will have less brightness than the rest of the picture. But though we see more of the body in binocular vision, it is only parts of vertical surfaces perpendicular to the line joining the eyes that are thus brought into view, the parts of similar horizontal surfaces remaining invisible as with one eye. It would require a pair of eyes placed vertically, that is, with the line joining them in a vertical direction, to enable us to see the horizontal as well as the vertical surfaces ; and it would require a pair of eyes inclined at all possible angles, that is, a ring of eyes $2\frac{1}{2}$ inches in diameter, to enable us to have a perfectly symmetrical view of the statue.

These observations will enable us to answer the question, whether or not a reduced copy of a statue, of precisely the same form in all its parts, will give us, either by monocular or binocular vision, a better view of it as a work of art. As it is the outer parts or surfaces of a large statue that

are invisible, its great outline and largest parts must be best seen in the reduced copy ; and consequently its relief, or third dimension in space, must be much greater in the reduced copy. This will be better understood if we suppose a *sphere* to be substituted for the statue. If the sphere exceeds in diameter the distance between the pupils of the right and left eye, or $2\frac{1}{2}$ inches, we shall not see a complete hemisphere, unless from an infinite distance. If the sphere is very much larger, we shall see only a segment, whose relief, in place of being equal to the radius of the sphere, is equal only to the versed sine of half the visible segment. Hence it is obvious that a reduced copy of a statue is not only better seen from more of its parts being visible, but is also seen in stronger relief.

On the Proper Position of the Sitter.

With these observations we are now prepared to explain the proper method of taking binocular portraits for the stereoscope.

The first and most important step is to fix upon the position of the sitter,—to select the best aspect of the face, and, what is of more importance than is generally supposed, to determine the best distance from the camera at which he should be placed. At a short distance certain parts of one face and figure which should be seen are concealed, and certain parts of other faces are concealed which should be seen. Prominent ears may be either hid or made less prominent by diminishing the distance, and if the sight of both ears is desirable the distance should be increased. Prominent features become less prominent by distance, and their influence in the picture is

also diminished by the increased vision which distance gives of the round of the head. The outline of the face and head varies essentially with the distance, and hence it is of great importance to choose the best. A long and narrow face requires to be viewed at a different distance from one that is short and round. Articles of dress even may have a better or a worse appearance according to the distance at which we see them.

Let us now suppose the proper distance to be *six feet*, and since it is impossible to give any rules for taking binocular portraits with large lenses we must assume a standard camera with a lens a quarter of an inch in diameter, as the only one which can give a correct picture as seen with one eye. If the portrait is wanted for a ring, a locket, or a binocular slide, its size is determined by its purpose, and the photographer must have a camera (which he has not) to produce these different pictures. His own camera will, no doubt, take a picture for a ring, a locket, or a binocular slide, but he does this by placing the sitter at different distances,—at a very great distance for the ring picture, at a considerable distance for the locket picture, and at a shorter distance for the binocular one ; but none of these distances are the distance which has been selected as the proper one. With a single lens camera, however, he requires only several quarter-inch lenses of different focal lengths to obtain the portrait of the sitter when placed at the proper distance from the camera.

In order to take binocular portraits for the stereoscope a binocular camera is required, having its lenses of such a focal length as to produce two equal pictures of the same object and of the proper size. Those in general use for

the lenticular stereoscope vary from 2.1 inches to 2.3 in breadth, and from 2.5 inches to 2.8 in height, the distance between similar points in the two pictures varying from 2.30 inches to 2.57, according to the different distances of the foreground and the remotest object in the picture.

Having fixed upon the proper distance of the sitter, which we shall suppose to be *six feet*,—a distance very suitable for examining a bust or a picture, we have now to take two portraits of him, which, when placed in the stereoscope, shall have the same relief and the same appearance as the sitter when viewed from the distance of *six feet*. This will be best done by a binocular camera, which we shall now describe.

The Binocular Camera.

This instrument differs from the common camera in having two lenses with the same aperture and focal length, for taking at the same instant the picture of the sitter as seen at the distance of *six feet*, or any other distance. As it is impossible to grind and polish two lenses, whether single or achromatic, of exactly the same focal length, even when we have the same glass for both, we must bisect a good lens, and use the two semi-lenses, ground into a circular form, in order to obtain pictures of exactly the same size and definition. These lenses should be placed with their diameters of bisection parallel to one another, and perpendicular to the horizon, at the distance of $2\frac{1}{2}$ inches, as shewn in Fig. 45, where *MN* is the camera, *L*, *L'* the two lenses, placed in two short tubes, so that by the usual mechanical means they can be directed to the sitter.

or have their axes converged upon him, as shewn in the Figure, where AB is the sitter, ab his image as given by the lens L , and $a'b'$ as given by the lens L' . These pictures

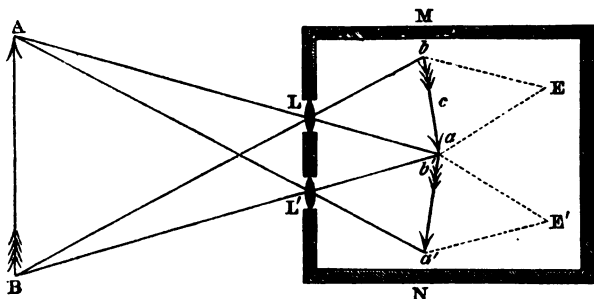


FIG. 45.

are obviously the very same that would be seen by the artist with his two eyes at L and L' , and as $ALB = aLb = a'L'b'$, the pictures will have the same apparent magnitude as the original, and will in no respect differ from it as seen by each eye from E, E' , Ea being equal to aL , and Ea' to aL .

Since the publication in 1849 of my description of the *binocular camera*, a similar instrument was proposed in Paris by a photographer, M. Quinet, who gave it the name of *Quinetoscope*, which, as the Abbé Moigno observes, means an instrument for seeing M. Quinet! I have not seen this camera, but, from the following notice of it by the Abbé Moigno, it does not appear to be different from mine :—" Nous avons été à la fois surpris et très-satisfait de retrouver dans le *Quinetoscope* la chambre binoculaire de notre ami Sir David Brewster, telle que nous l'avons décrite après lui il y a dix-huit mois dans notre brochure

intitulée *Stéréoscope*." Continuing to speak of M. Quinet's camera, the Abbé is led to criticise unjustly what he calls the limitation of the instrument:—"En un mot, ce charmant appareil est aussi bien construit qu'il peut être, et nous désirons ardemment qu'il se répand assez pour récompenser M. Quinet de son habileté et de ses peines. Employé dans les limites fixées à l'avance par son véritable inventeur, Sir David Brewster; c'est-à-dire, employé à reproduire des objets de petite et moyenne grandeur, il donnera assez beaux résultats. Il ne pourra pas servir, évidemment, il ne donnera pas bien l'effet stéréoscopique voulu, quand on voudra l'appliquer à de très-grands objets, on a des vues ou paysages pris d'une très-grande distance; mais il est de la nature des œuvres humaines d'être essentiellement bornées."¹ This criticism on the limitation of the camera is wholly incorrect; and it will be made apparent, in a future part of the Chapter, that for objects of all sizes and at all distances the binocular camera gives the very representations which we see, and that other methods, referred to as superior, give unreal and untruthful pictures, for the purpose of producing a startling relief.

In stating, as he subsequently does, that the angles at which the pictures should be taken "are too vaguely indicated by theory,"² the Abbé cannot have appealed to his own optical knowledge, but must have trusted to the practice of Mr. Claudet, who asserts "that there cannot be any rule for fixing the binocular angle of camera obscuras. *It is a matter of taste and artistic illusion.*"³ No question of science can be a matter of taste, and no

¹ See *Cosmos*, vol. ii. pp. 622, 624.

² *Id.* vol. vii. p. 494.

³ *Id.* vol. iii. p. 658.

illusion can be artistic which is a misrepresentation of nature.

When the artist has not a binocular camera he must place his single camera successively in such positions that the axis of his lens may have the directions EL , EL' making an angle equal to LCI' , the angle which the distance between the eyes subtends at the distance of the sitter from the lenses. This angle is found by the following formula :—

$$\text{Tang. } \frac{1}{2} A = \frac{\frac{1}{2} d}{D} = \frac{1.25}{D}$$

d being the distance between the eyes, D the distance of the sitter, and A the angle which the distance between the eyes, $= 2.5$, subtends at the distance of the sitter. These angles for different distances are given in the following table :—

D = Distance of Camera from the Sitter.			A = Angle formed by the two directions of the Camera.
5 inches,	.	.	28° 6'
6,	.	.	23 32
7,	.	.	20 14
8,	.	.	17 46
9,	.	.	15 48
10,	.	.	14 15
11,	.	.	13 0
12, 1 foot,	.	.	11 54
13,	.	.	11 0
14,	.	.	10 17
15,	.	.	9 32
16,	.	.	8 56
17,	.	.	8 24
18,	.	.	7 56
19,	.	.	7 31
20,	.	.	7 10
24, 2 feet,	.	.	5 58
30,	.	.	4 46

D = Distance of Camera from the Sitter.	A = Angle formed by the two directions of the Camera.
36 inches, 3 feet, . . .	3° 59'
42, . . .	3 25
48, 4 feet, . . .	2 59
54, . . .	2 39
60, 5 feet, . . .	2 23
72, 6 feet, . . .	1 59
84, 7 feet, . . .	1 42
96, 8 feet, . . .	1 30
108, 9 feet, . . .	1 20
120, 10 feet, . . .	1 12

The numbers given in the greater part of the preceding table can be of use only when we wish to take binocular pictures of small objects placed at short distances from cameras of a diminutive size. In photographic portraiture they are of no use. The correct angle for a distance of *six* feet must not exceed *two* degrees,—for a distance of *eight* feet, *one and a half* degrees, and for a distance of *ten* feet, *one and a fifth* degree. Mr. Wheatstone has given quite a different rule. He makes the angle to depend, not on the distance of the sitter from the camera, but *on the distance of the binocular picture in the stereoscope from the eyes of the observer!* According to the rule which I have demonstrated, the angle of convergency for a distance of *six* feet must be 1° 59', whereas in a stereoscope of any kind, with the pictures *six* inches from the eyes, Mr. Wheatstone makes it 23° 32'! As such a difference is a scandal to science, we must endeavour to place the subject in its true light, and it will be interesting to observe how the problem has been dealt with by the professional photographer. The following is Mr. Wheatstone's explanation of his own rule, or rather his mode of stating it :—

"With respect," says he, "to the means of preparing the binocular photographs, (and in this term I include both Talbotypes and Daguerreotypes,) little requires to be said beyond a few directions as to the proper positions in which it is *necessary* to place the camera in order to obtain the two required projections.

"We will suppose that the binocular pictures are required to be seen in the stereoscope at a distance of eight inches before the eyes, in which case the convergence of the optic axes is about 18° . To obtain the proper projections for this distance, the camera must be placed with its lens accurately directed towards the object successively in two points of the circumference of a circle, of which the object is the centre, and the points at which the camera is so placed must have the angular distance of 18° from each other, exactly that of the optic axes in the stereoscope. The distance of the camera from the object may be taken arbitrarily, for so long as the same angle is employed, whatever that distance may be, *the picture will exhibit in the stereoscope the same relief*, and be seen at the same distance of eight inches, *only* the magnitude of the picture will appear different. Miniature stereoscopic representations of buildings and full-sized statues are, therefore, obtained merely by taking the two projections of the object from a considerable distance, *but at the same time as if the object were only eight inches distant*, that is, at an angle of 18° ."¹

Such is Mr. Wheatstone's rule, for which he has assigned no reason whatever. In describing the binocular camera, in which the lenses must be only $2\frac{1}{2}$ inches distant for portraits, I have shewn that the pictures which it gives are

¹ *Phil. Trans.*, 1852, p. 7.

perfect representations of the original, and therefore pictures taken with *lenses* or cameras at any other distance, must be different from those which are seen by the artist looking at the sitter from his camera. They are, doubtless, both pictures of the sitter, but the picture taken by Mr. Wheatstone's rule is one which no man ever saw or can see, until he can place his eyes at the distance of *twenty inches* ! It is, in short, the picture of a living doll, in which parts are seen which are never seen in society, and parts hid which are always seen.

In order to throw some light upon his views, Mr. Wheatstone got "a number of Daguerreotypes of the same bust taken at a variety of different angles, so that he was enabled to place in the stereoscope two pictures taken at any angular distance from 2° to 18° , the former corresponding to a distance of about six feet, and the latter to a distance of about eight inches." In those taken at 2° , (the proper angle,) there is "an undue elongation of lines joining two unequally distant points, so that all the features of a bust appear to be exaggerated in depth ;" while in those taken at 18° , "there is an undue shortening of the same lines, so that the appearance of a bas-relief is obtained from the two projections of the bust, the apparent dimensions in breadth and height remaining in both cases the same."

Although Mr. Wheatstone speaks thus decidedly of the relative effect produced by combining pictures taken at $2\frac{1}{2}^{\circ}$ and 18° , yet in the very next paragraph he makes statements entirely incompatible with his previous observations. "When the optic axes," he says, "are parallel, *in strictness* there should be no difference between the pictures presented to each eye, and in this case *there would be no binocular*

relief, but I find *that an excellent effect* is produced when the axes are nearly parallel, by pictures taken at an inclination of 7° or 8° , and even a difference of 16° or 17° *has no decidedly bad effect!*"

That Mr. Wheatstone observed all these contradictory facts we do not doubt, but why he observed them, and what was their cause, is a question of scientific as well as of practical importance. Mr. Wheatstone was not aware¹ that the Daguerreotype pictures which he was combining, taken with *large lenses*, were not pictures as seen with two human eyes, but were actually binocular and multocular monstrosities, entirely unfit for the experiments he was carrying on, and therefore incapable of testing the only true method of taking binocular pictures which we have already explained.

Had Mr. Wheatstone combined pictures, each of which was a correct monocular picture, as seen with each eye, and as taken with a small aperture or a small lens, he would have found no discrepancy between the results of observation and of science. From the same cause, we presume, namely, the use of multocular pictures, Mr. Alfred Smee² has been led to a singular method of taking binocular ones. In one place he implicitly adopts Mr. Wheatstone's erroneous rule. "The pictures for the stereoscope," he says, "are taken at two stations, at a greater or less distance apart, according to the distance at which they are to be viewed. For a distance of 8 inches the two pictures are taken at angles of 18° , for 13 inches 10° , for 18 inches

¹ Mr. Wheatstone's paper was published before I had pointed out the deformities produced by large lenses. See p. 130.

² *The Eye in Health and Disease*, by Alfred Smee, 2d edit. 1854, pp. 85-95.

8°, and for 4 feet 4°." But when he comes to describe his own method he seems to know and to follow the true method, if we rightly understand his meaning. "To obtain a binocular picture of anybody," he says, "the camera must be employed to take half the impression, and then it must be moved in the arc of a circle of which the distance from the camera to the *point of sight*¹ is the radius for about 2½ inches when a second picture is taken, and the two impressions conjointly form one binocular picture. There are many ways by which this result may be obtained. A spot may be placed on the ground-glass on which the point of sight should be made exactly to fall. The camera may then be moved 2½ inches, and adjusted till the point of sight falls again upon the same spot on the ground-glass, when, if the camera has been moved in a true horizontal plane *the effect of the double picture will be perfect.*" This is precisely the true method of taking binocular pictures which we had given long before, but it is true only when small lenses are used. In order to obtain this motion in the true arc of a circle the camera was moved on two cones which converged to the point of sight, and Mr. Smeë thus obtained pictures of the usual character. But in making these experiments he was led to take pictures *when the camera was in continual motion backwards and forwards for 2½ inches*, and he remarks that "*in this case the picture was even more beautiful than when the two images were superimposed!*" "This experiment," he adds, "is very remarkable, for who would have thought formerly that a picture could possibly have

¹ This expression has a different meaning in perspective. We understand it to mean here the point of the sitter or object, which is to be the centre of the picture.

been made with a camera in continual motion ? Nevertheless we accomplish it every day with ease, and the character of the likeness is wonderfully improved by it." We have now left the regions of science, and have to adjudicate on a matter of opinion and taste. Mr. Smee has been so kind as to send me a picture thus taken. It is a good photograph with features enlarged in all azimuths, but it has no other relief than that which we have described as monocular.

A singular effect of combining pictures taken at extreme angles has been noticed by Admiral Lageol. Having taken the portrait of one of his friends when his eyes were directed to the object-glass of the camera, the Admiral made him look at an object 45° ! to the right, and took a second picture. When these pictures were placed in the stereoscope, and viewed "without ceasing, turning first to the right and then to the left, the eyes of the portrait follow this motion as if they were animated."¹ This fact must have been noticed in common stereoscopic portraits by every person who has viewed them alternately with each eye, but it is not merely the eyes which move. The nose, and indeed every feature, changes its place, or, to speak more correctly, the whole figure leaps from the one binocular position into the other. As it is unpleasant to open and shut the eyes alternately, the same effect may be more agreeably produced in ordinary portraits by merely intercepting the light which falls upon each picture, or by making an opaque screen pass quickly between the eyes and the lens, or immediately below the lens, so as to give successive vision of the pictures with each eye, and with

¹ *Cosmos*, Feb. 29, 1856, vol. viii. p. 202.

both. The motion of the light reflected from the round eyeball has often a striking effect.

From these discussions, our readers will observe that the science, as well as the art of binocular portraiture for the stereoscope, is in a transition state in which it cannot long remain. The photographer who works with a very large lens chooses an angle which gives the least unfavourable results ; his rival, with a lens of less size, chooses, on the same principle, a different angle ; and the public, who are no judges of the result, are delighted with their pictures in relief, and when their noses are either pulled from their face, or flattened upon their cheek, or when an arm or a limb threatens to escape from their articulation, they are assured that nature and not art is to blame.

We come now to consider under what circumstances the photographer may place the lenses of his binocular camera at a greater distance than $2\frac{1}{2}$ inches, or his two cameras at a greater angle than that which we have fixed.

1. In taking family portraits for the stereoscope, the cameras must be placed at an angle of 2° for 6 feet, when the binocular camera is not used.

2. In taking binocular pictures of any object whatever, when we wish to see them exactly as we do with our two eyes, we must adopt the same method.

3. If a portrait is wanted to assist a sculptor in modelling a statue, a great angle might be adopted, in order to shew more of the head. But in this case the best way would be to take the correct social likeness, and then take photographs of the head in different azimuths.

If we wish to have a greater degree of relief than we have with our two eyes, either in viewing colossal statues,

or buildings, or landscapes, where the deviation from nature does not, as in the human face, affect the expression, or injure the effect, we must increase the distance of the lenses in the binocular camera, or the angle of direction of the common camera. Let us take the case of a colossal statue 10 feet wide, and suppose that dissimilar drawings of it about *three* inches wide are required for the stereoscope. These drawings are *forty* times narrower than the statue, and must be taken at such a distance, that with the binocular camera the relief would be almost evanescent. We must therefore suppose the statue to be reduced n times, and place the semi-lenses at the distance $n \times 2\frac{1}{2}$ inches. If $n = 10$, the statue 10 feet wide will be reduced to $\frac{1}{10}$, or to 1 foot, and $n \times 2\frac{1}{2}$, or the distance of the semi-lenses will be 25 inches. With the lenses at this distance, the dissimilar pictures of the statue will reproduce, when combined, a statue one foot wide, which will have exactly the same appearance and relief as if we had viewed the colossal statue with eyes 25 inches distant. But the reproduced statue will have also the same appearance and relief as a statue a foot wide reduced from the colossal one with mathematical precision, and it will therefore be a better or more relieved representation of the work of art than if we had viewed the colossal original with our own eyes, either under a greater, an equal, or a less angle of apparent magnitude.

We have supposed that a statue a foot broad will be seen in proper relief by binocular vision ; but it remains to be decided whether or not it would be more advantageously seen if reduced with mathematical precision to a breadth of $2\frac{1}{2}$ inches, the width of the eyes, which gives the vision of

a hemisphere $2\frac{1}{2}$ inches in diameter with the most perfect relief.¹ If we adopt this principle, and call B the breadth of the statue of which we require dissimilar pictures, we must make $n = \frac{B}{2\frac{1}{2}}$, and $n \times 2\frac{1}{2} = B$, that is, the distance of the semi-lenses in the binocular camera, or of the lenses in two cameras, must be made equal to the breadth of the statue.

In concluding this chapter, it may be proper to remark, that unless we require an increased relief for some special purpose, landscapes and buildings should be taken with the normal binocular camera, that is, with its lenses $2\frac{1}{2}$ inches distant. Scenery of every kind, whether of the picturesque, or of the sublime, cannot be made more beautiful or grand than it is when seen by the traveller himself. To add an artificial relief is but a trick which may startle the vulgar, but cannot gratify the lover of what is true in nature and in art.

The Single Lens Binocular Camera.

As every photographer possesses a camera with a lens between $2\frac{1}{2}$ and 3 inches in diameter, it may be useful to him to know how he may convert it into a binocular instrument.

In a cover for the lens take two points equidistant from each other, and make two apertures, c, d , Fig. 43, $\frac{2}{10}$ ths of an inch in diameter, or of any larger size that may be thought proper, though $\frac{2}{10}$ is the proper size. Place the cover on the end of the tube, and bring the line joining the apertures into a horizontal position. Closing one aperture, take the picture of the sitter, or of the statue, through the

¹ It is only in a horizontal direction that we can see 180° of the hemisphere. We would require a circle of eyes $2\frac{1}{2}$ inches distant to see a complete hemisphere.

other, and when the picture is shifted aside by the usual contrivances for this purpose, take the picture through the other aperture. These will be good binocular portraits, fitted for any stereoscope, but particularly for the Achromatic Reading Glass Stereoscope. If greater relief is wanted, it may be obtained in larger lenses by placing the two apertures at the greatest distance which the diameter of the lens will permit.

The Binocular Camera made the Stereoscope.

If the lenses of the binocular camera, when they are whole lenses, be made to separate a little, so that the distance between the centres of their inner halves may be equal to $2\frac{1}{2}$ inches, they become a lenticular stereoscope, in which we may view the pictures which they themselves create. The binocular pictures are placed in the camera in the very place where their negatives were formed, and the observer, looking through the halves of his camera lenses, will see the pictures united and in relief. If the binocular camera is made of semi-lenses, we have only to place them with their thin edges facing each other to obtain the same result. It will appear, from the discussions in the following chapter, that such a stereoscope, independently of its being achromatic, if the camera is achromatic, will be the most perfect of stereoscopic instruments.

The preceding methods are equally applicable to landscapes, machines, and instruments, and to solid constructions of every kind, whether they be the production of nature or of art.¹

¹ See Chapters X. and XI.

CHAPTER IX.

ON THE ADAPTATION OF THE PICTURES TO THE STEREOSCOPE.
—THEIR SIZE, POSITION, AND ILLUMINATION.

HAVING described the various forms of the stereoscope, and the method of taking the binocular portraits and pictures to which it is to be applied, we have now to consider the relation that ought to exist between the instrument and the pictures,—a subject which has not been noticed by preceding writers.

If we unite two dissimilar pictures by the simple convergency of the optical axes, we shall observe a certain degree of relief, at a certain distance of the eyes from the pictures. If we diminish the distance, the relief diminishes, and if we increase it, it increases. In like manner, if we view the dissimilar pictures in the lenticular stereoscope, they have a certain degree of relief; but if we use lenses of a higher magnifying power, so as to bring the eyes nearer the pictures, the relief will diminish, and if we use lenses of a less magnifying power, the relief will increase. By bringing the eyes nearer the pictures, which we do by magnifying them as well as by approaching them, we increase the distance between similar points of the two pictures, and therefore the distance of these points, when united, from

any plane in the picture, that is, its relief will be diminished. For the same reason, the diminution of the distance between similar points by the removal of the eyes from the picture, will produce an increase of relief. This will be readily understood if we suppose the eyes R, L , in Fig. 24, to be brought nearer the plane MN , to $R' L'$, the points 1, 1 and 2, 2 will be united at points nearer MN than when the eyes were at R, L , and consequently their relief diminished.

Now we have seen, that in taking portraits, as explained in Fig. 45, we view the two pictures, $ab, a'b'$, with the eyes at E and E' , exactly, and with the same relief in the air, as when we saw the original AB , from L, L' , and therefore Ec is the distance at which the dissimilar pictures should be viewed in the stereoscope, in order that we may see the different parts of the solid figure under their proper relief. But the distance $Ec = Lc$ is the conjugate focal length of the lens L , if one lens is used, or the conjugate equivalent focal length, if two achromatic lenses are used; and consequently every picture taken for the stereoscope should be taken by a camera, the conjugate focal length of whose lens corresponding to the distance of the sitter, is equal to *five* inches, when it is to be used in the common stereoscope, which has generally that depth.

Between the pictures and the purely optical part of the stereoscope, there are other relations of very considerable importance. The exclusion of all external objects or sources of light, excepting that which illuminates the pictures, is a point of essential importance, though its advantages have never been appreciated. The spectacle stereoscope held in the hand, the reflecting stereoscope, and the open lenticular

stereoscope, are all, in this respect, defective. The binocular pictures must be placed in a dark box, in order to produce their full effect ; and it would be a great improvement on the lenticular stereoscope, if, on the left and right side of each eye-tube, a piece of brass were to be placed, so as to prevent any light from entering the left angle of the left eye, and the right angle of the right eye.¹ The eyes, thus protected from the action of all external light, and seeing nothing but the picture, will see it with a distinctness and brilliancy which could not otherwise be obtained.

The proper illumination of the picture, when seen by reflected light, is also a point of essential importance. The method universally adopted in the lenticular stereoscope is not good, and is not the one which I found to be the best, and which I employed in the first-constructed instruments. The light which falls upon the picture is prevented from reaching the observer only by its being incident at an angle greater or less than the angle of reflexion which would carry it to his eyes. A portion of the scattered light, however, does reach the eye, and in Daguerreotypes especially, when any part of the surface is injured, the injury, or any other imperfection in the plate, is more distinctly seen. The illumination should be lateral, either by a different form of window in the front, or by openings on the two sides, or by both these methods.

When the lenticular stereoscope is thus fitted up, and the pictures in this manner illuminated, the difference of effect is equally great as it is between a picture as commonly

¹ When any external light falls upon the eye, its picture is reflected back from the metallic surface of the Daguerreotype, and a negative picture of the part of the Daguerreotype opposite each eye is mixed with the positive picture of the same part.

seen, and the same picture exhibited as a panorama or a diorama, in which no light reaches the eyes but that which radiates from the painting itself, the reflexion from the varnish being removed by oblique or lateral illumination.

The great value of transparent binocular slides, when the picture is to be upon glass, is obvious from the preceding considerations. The illumination is uniform and excellent, but care must be taken to have the ground glass in front of the picture, or the paper, when it is used, of a very fine grain, so that it may throw no black specks upon the sky or the lights of the picture. Another advantage of the transparent slides is, that the pictures are better protected from injury than those upon paper.

It is obvious from these considerations that the *size* of the pictures is determined, as well as the distance at which they are to be viewed. Much ignorance prevails upon this subject, both among practical photographers and optical writers. Large binocular pictures have been spoken of as desirable productions, and it has been asserted, and claimed too, as a valuable property of the reflecting stereoscope, that it allows us to use larger pictures than other instruments. There never was a greater mistake. If we take a large picture for the stereoscope we must place it at a great distance from the eye, and consequently use a large stereoscope. A small picture, seen distinctly near the eye, is the very same thing as a large picture seen at a greater distance. The size of a picture, speaking optically and correctly, is measured by the angle which it subtends at the eye, that is its apparent magnitude. A portrait three inches high, for example, and placed in the lenticular stereoscope five inches from the eye, has the same apparent size as a Kit

Cat portrait in oil the size of life, three feet high, seen at the distance of five feet, the distance at which it is commonly examined ; and if we increase the magnifying power so as to see the three-inch picture at the distance of two inches, it will have the same apparent size as the three feet oil portrait seen at the distance of two feet. If the pictures used in the stereoscope were imperfect pictures that would not bear being magnified, it would be improper to use them ; but the Daguerreotypes, and the transparent pictures, which are taken by the first artists, for the lenticular stereoscope, will bear a magnifying power ten times greater than that which is applied to them.

If we take a large picture for the stereoscope, we are compelled by pictorial truth to place it at a distance from the eye equal to the equivalent focal distance of the camera. Every picture in every camera has the same apparent magnitude as the object which it represents ; whether it be a human figure, or the most distant landscape ; and if we desire to see it in its true relief in the stereoscope, we must place it at a distance from the eye equal to the focal length of the lens, whether it be an inch or a foot high. There is, therefore, nothing gained by using large pictures. There is, on the contrary, much inconvenience in their use. They are in themselves less portable, and require a larger stereoscope ; and we believe, no person whatever, who is acquainted with the perfection and beauty of the binocular slides in universal use, would either incur the expense, or take the trouble of using pictures of a larger size.

In the beautiful combination of lenticular stereoscopes, which was exhibited by Mr. Claudet, Mr. Williams, and others, in the Paris Exhibition, and into which six or eight

CHAPTER X.

APPLICATION OF THE STEREOSCOPE TO PAINTING.

HAVING explained the only true method of taking binocular portraits which will appear in correct relief when placed in the stereoscope, we shall proceed in this chapter to point out the application of the stereoscope to the art of painting in all its branches. In doing this we must not forget how much the stereoscope owes to photography, and how much the arts of design might reasonably expect from the solar pencil, when rightly guided, even if the stereoscope had never been invented.

When the processes of the Daguerreotype and Talbotype, the sister arts of Photography, were first given to the world, it was the expectation of some, and the dread of others, that the excellence and correctness of their delineations would cast into the shade the less truthful representations of the portrait and the landscape painter. An invention which supersedes animal power, or even the professional labour of man, might have been justly hailed as a social blessing, but an art which should supersede the efforts of genius, and interfere with the exercise of those creative powers which represent to us what is beautiful and sublime in nature, would, if such a thing were possible, be a social evil.

The arts of painting, sculpture, and architecture have in

every age, and in every region of civilisation, called into exercise the loftiest genius and the deepest reason of man. Consecrated by piety, and hallowed by affection, the choicest productions of the pencil and the chisel have been preserved by the liberality of individuals and the munificence of princes, while the palaces of sovereigns, the edifices of social life, the temples of religion, the watch-towers of war, the obelisks of fame, and the mausolea of domestic grief, stand under the azure cupola of heaven, to attest by their living beauty, or their ruined grandeur, the genius and liberality which gave them birth. To the cultivation and patronage of such noble arts, the vanity, the hopes, and the holiest affections of man stand irrevocably pledged ; and we should deplore any invention or discovery, or any tide in the nation's taste, which should paralyse the artist's pencil, or break the sculptor's chisel, or divert into new channels the genius which wields them. But instead of superseding the arts of design, photography will but supply them with new materials,—with collections of costume,—with studies of drapery and of forms, and with scenes in life, and facts in nature, which, if they possess at all, they possess imperfectly, and without which art must be stationary, if she does not languish and decline.

Sentiments analogous to these have been more professionally expressed by M. Delaroche, a distinguished French artist,—by Sir Charles Eastlake, whose taste and knowledge of art is unrivalled,—and by Mr. Ruskin, who has already given laws to art, and whose genius is destined to elevate and to reform it. M. Delaroche considers photography “as carrying to such perfection certain of the essential principles of art, that they must become subjects of study

and observation, even to the most accomplished artist." "The finish of inconceivable minuteness," he says, "disturbs in no respect the repose of the masses, nor impairs in any way the general effect. . . . The correctness of the lines, the precision of the forms in the designs of M. Daguerre, are as perfect as it is possible they can be, and yet, at the same time, we discover in them a broad and energetic manner, and a whole equally rich in hue and in effect. The painter will obtain by this process a quick method of making collections of studies, which he could not otherwise procure without much time and labour, and in a style very far inferior, whatever might be his talents in other respects." In the same spirit, Mr. Ruskin¹ considers "the art of photography as enabling us to obtain as many memoranda of the facts of nature as we need ;" and long before Mr. Talbot taught us to fix upon paper the pictures of the camera obscura, the Rev. John Thomson, one of the most distinguished of our Scottish landscape painters, studied, in one of these instruments, the forms and colours of the scenes which he was to represent. Other artists, both in portrait and in landscape, now avail themselves of photography, both as an auxiliary and a guide in their profession ; but there are certain difficulties and imperfections in the art itself, and so many precautions required in its right application, whether we use its pictures single, as representations on a plane, or take them binocularly, to be raised into relief by the stereoscope, that we must draw from the principles of optics the only rules which can be of real services to the arts of design.

In painting a landscape, a building, a figure, or a group

¹ *Modern Painters*, vol. iii., Preface, pp. 11, 12.

of figures, the object of the artist is to represent it on his canvas *just as he sees it*, having previously selected the best point of view, and marked for omission or improvement what is not beautiful, or what would interfere with the effect of his picture as a work of high art. His first step, therefore, is to fix upon the size of his canvas, or the distance at which the picture is to be seen, which determines its size. His own eye is a camera obscura, and the relation between the picture or image on its retina is such, that if we could view it from the centre of curvature of the retina, (the centre of visible direction,) a distance of half an inch, it would have precisely the same apparent magnitude as the object of which it is the image. Let us now suppose that the artist wishes to avail himself of the picture in the camera obscura as received either on paper or ground glass, or of a photograph of the scene he is to paint. He must make use of a camera whose focal length is equal to the distance at which his picture is to be seen, and when the picture thus taken is viewed at this distance (suppose *two feet*) it will, as a whole, and in all its parts, have the same apparent magnitude as the original object. This will be understood from Fig. 47, in which we may suppose H to be the lens of the camera, RB the object, and $H\gamma'$ the distance at which it is to be viewed. The size of the picture taken with a lens at H , whose focal length is $H\gamma'$, will be $b'r'$, and an eye placed at H will see the picture $b'r'$ under an angle $b'Hr'$, equal to the angle RHB , under which the real object RB was seen by the artist from H . In like manner, a larger picture, $b\gamma r$, taken by a camera the focal distance of whose lens at H is $H\gamma$, will be an accurate representation of the object RB , when viewed from H , and of

the same apparent magnitude. If either of these pictures, $b'r'$ or br , are viewed from greater or less distances than Hy , or Hy' , they will not be correct representations of the

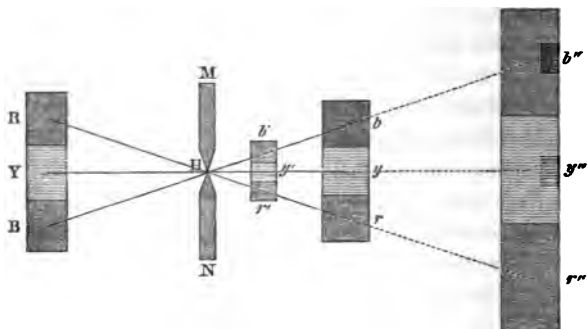


FIG. 47.

object BB , either in apparent magnitude or form. That they will be of a different apparent magnitude, greater when viewed at less distances than Hy' , Hy , and less when viewed at greater distances, is too obvious to require any illustration. That they will differ in form, or in the relative apparent size of their parts, has, so far as I know, not been conjectured. In order to shew this, let us suppose a man *six* feet high to occupy the foreground, and another of the same size to be placed in the middle distance, the distance of the two from the artist being ten and twenty feet. The apparent magnitudes of these two men on the photograph will be as two to one; and if we look at it at any distance greater or less than the focal length Hy' of the lens, the same proportion of two to one will be preserved, whereas if we look at the original figures at a greater or less distance from them than the place of the artist, the

ratio of their apparent magnitudes will be altered. If the artist, for example, advances five feet, the nearest man will be five feet distant and the other fifteen feet, so that their apparent magnitude will now be as three to one.

The same observations apply to a portrait of the human face. In looking at a human profile let us suppose the breadth of the nose to be one inch, that of the ear one inch, and that we view this profile at the distance of *three* feet from the ear, which is two inches nearer the observer than the nose. The apparent magnitude of the ear and nose will be as thirty-eight to thirty-six inches, whereas if we view the profile from the distance of *one* foot the ratio will be as fourteen to twelve, that is, the ear will be increased in apparent size more than the nose. Hence it follows that all pictures should be viewed under the same angle of apparent magnitude under which they were seen by the artist as taken photographically, for if we view them at a greater or less angle than this we do not see the same picture as when we looked at the original landscape or portrait, under the same angle of apparent magnitude.

From the observations made in the preceding Chapter on photographic and stereoscopic portraiture, the reader must have already drawn the inference that the same landscape or building, seen at different distances, varies essentially in its character,—beauties disclosing themselves and defects disappearing as we approach or recede from them. The picture in the camera, therefore, as used by Mr. Thomson, or, what is still better, with the exception of colour, the photograph obtained by the same instrument, will supply the artist with all the general materials for his picture. The photograph will differ considerably from any

sketch which the artist may have himself made, owing to certain optical illusions to which his eye is subject. The hills and other vertical lines in the distance will be lower in the photograph than in his sketch.¹ The vertical lines of buildings will converge upwards in the photograph, as they ought to do, in receding from the eye ; and in the same picture there will be a confusion, as we shall afterwards shew, in the delineation of near and minute objects in the foreground, increasing with the size of the lens which he has employed.

In his admirable chapter "On Finish," Mr. Ruskin has established, beyond a doubt, the most important principle in the art of painting. "The finishing of nature," he states, "consists not in the smoothing of surface, but the filling of space, and the multiplication of life and thought ;" and hence he draws the conclusion, that "finishing means, in art, simply telling more truth." Titian, Tintoret, Bellini, and Veronese have, as he has shewn, wrought upon this principle, delineating vein by vein in the leaf of the vine, petal by petal in the borage-blossoms, the very snail-shells on the ground, the stripe of black bark in the birch-tree, and the clusters of the ivy-leaved toad-flax in the rents of their walls ; and we have seen that a modern artist, Delacroix, considers a *finish* of *inconceivable minuteness* as

¹ Sir Francis Chantrey, the celebrated sculptor, shewed me, many years ago, a Sketch-Book, containing numerous drawings which he had made with the *Camera Lucida*, while travelling from London to Edinburgh by the Lakes. He pointed out to me the flatness, or rather lowness, of hills, which to his own eye appeared much higher, but which, notwithstanding, gave to him the idea of a greater elevation. In order to put this opinion to the test of experiment, I had drawings made by a skilful artist of the three Eildon hills opposite my residence on the Tweed, and was surprised to obtain, by comparing them with their true perspective outlines, a striking confirmation of the observation made by Sir Francis Chantrey.

neither disturbing the repose of the masses, nor interfering with the general effect in a picture.

The Pre-Raphaelites, therefore, may appeal to high authority for the cardinal doctrine of their creed ; and whatever be their errors in judgment or in taste, they have inaugurated a revolution which will release art from its fetters, and give it a freer and a nobler aim. Nature is too grand in her minuteness, and too beautiful in her humility, to be overlooked in the poetry of art. If her tenderest and most delicate forms are worthy of admiration, she will demand from the artist his highest powers of design. If the living organizations of the teeming earth, upon which we hourly tread, are matchless in structure, and fascinating in colour, the palette of the painter must surrender to them its choicest tints. In the foreground of the highest art, the snail-shell may inoffensively creep from beneath the withered leaf or the living blade ; the harebell and the violet may claim a place in the sylvan dell ; the moss may display its tiny frond, the gnarled oak or the twisted pine may demand the recognition of the botanist, while the castle wall rises in grandeur behind them, and the gigantic cliffs or the lofty mountain range terminate the scene.

If these views are sound, the man of taste will no longer endure slovenliness in art. He will demand truth as well as beauty in the landscape ; and that painter may change his profession who cannot impress geology upon his rocks, and botany upon his plants and trees, or who refuses to display, upon his summer or his autumn tablet, the green crop as well as the growing and the gathered harvest. Thus enlarged in its powers and elevated in its purposes, the art of painting will be invested with a new character, demand-

ing from its votaries higher skill and more extended knowledge. In former times, the minute and accurate delineation of nature was a task almost impossible, requiring an amount of toil which could hardly be repaid even when slightly performed ; but science has now furnished art with the most perfect means of arresting, in their most delicate forms, every object, however minute, that can enter into the composition of a picture. These means are the arts of photography and stereoscopic re-combination, when rightly directed, and it is the object of the present chapter to shew how the artist may best avail himself of their valuable and indispensable aid.

Every country and district, and even different parts of the same district, have a Flora and Geology peculiar to themselves ; and the artist who undertakes to represent its beauties owes to truth the same obligations as the botanist who is to describe its plants, or the mineralogist its rocks and stones. The critic could not, in former times, expect more details from his unaided pencil than it has generally furnished ; but with the means now at his command, he must collect, like the naturalist, all the materials for his subject. After the camera has given him the great features of his landscape, he must appeal to it for accurate delineations of its minuter parts,—the trunks, and stems, and leafage of his trees—the dipping strata of its sandstone beds—the contortions of its kneaded gneiss, or the ruder features of its trap and its granite. For the most important of these details he will find the camera, as at present constructed, of little service. It is fitted only to copy *surfaces* ; and therefore, when directed to solid bodies, such as living beings, statues, &c., it gives false and hideous representa-

tions of them, as I have shewn in a preceding chapter. It is peculiarly defective when applied to parts of bodies at different distances from it, and of a less diameter than the lens. The photograph of a cube taken by a lens of a greater diameter, will display *five* of its sides in a position, when its true perspective representation is simply a single square of its surface. When applied to trees, and shrubs, and flowers, its pictures are still more unsatisfactory. Every stem and leaf smaller than the lens, though absolutely opaque, is transparent, and leaves and stems behind and beyond are seen like ghosts through the photographic image.

This will be understood from Fig. 48, in which LL is the

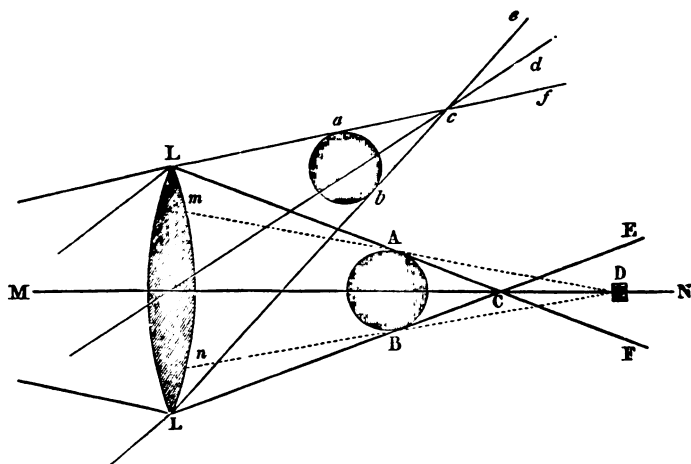


FIG. 48.

lens of the camera, AB the breadth of the trunk or stem of a tree less than LL in width. Draw LA, LB, touching AB in the points A, B, and crossing at c. Objects behind AB,

and placed within the angle $\angle ACB$, will not have any images of them formed by the lens LL , because none of the rays which proceed from them can fall upon the lens, but objects placed within the angle $\angle ECF$, however remote be their distance, will have images of them formed by the lens. If D , for example, be a leaf or a fruit, or a portion of a branch, the rays which it emits will fall upon the portions Lm, Ln of the lens, determined by drawing Dm, Dn touching AB , and an image of it will be formed in the centre of the photographic image of AB , as if AB were transparent. This image will be formed by all the portions of the surface of the lens on which the shadow of AB , formed by rays emanating from D , would not fall. If the object D is more remote, the shadow of AB will diminish in size, and the image of the object will be formed by a greater portion of the lens. If the sun were to be in the direction MN , his image would appear in the centre of the trunk or stem, corresponding to AB , Fig. 49.

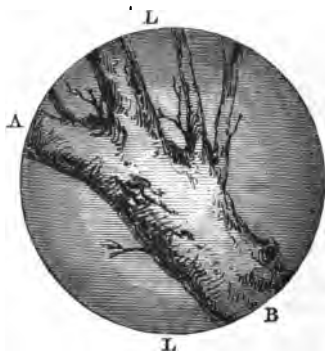


FIG. 49.

If the stem occupies any other position, ab , Fig. 48, in the landscape, objects, such as d , within the angle $\angle ecf$, will have

images of them formed within the corresponding portion of the trunk or stem. Hence, if *AB*, Fig. 49, represents the shadow of the stem across the lens *LL*, the image of any object, which if luminous would give this shadow, will be formed within the photographic image of the stem, and as every part of it may have branches, or leaves, or fruit behind it, its photographs will be filled with their pictures, which will have the same distinctness as other equidistant parts of the landscape.

These observations are applicable to the limbs and slender parts of animate and inanimate figures, when they are of a less size than the lens with which their photograph is taken. They will be transparent to all objects behind them, and their true forms and shades cannot be taken with the cameras now in use.¹

In order, therefore, to collect from nature the materials of his profession, the artist must use a camera with a lens not much larger than the pupil of his eye, and with such an instrument he will obtain the most correct drawings of the trunks and stems of trees, of the texture and markings of their bark, of the form of their leaves, and of all those peculiarities of structure and of leafage by which alone the trees of the forest can be distinguished. In like manner, he will obtain the most correct representations of the rocks and precipices, and the individual stones² which may enter

¹ By using large lenses, we may obtain the picture of an object within the picture of an opaque one in front of it; and with a telescope, we may see through opaque objects of a certain size. Many singular experiments may be made by taking photographs of solid objects, simple or compound, with lenses larger than the objects themselves.

² In a landscape by Mr. Waller Paton, called the "Highland Stream," now in the Edinburgh Exhibition, the foreground consists principally of a bed of water-worn stones, on the margin of a pool at the bottom of a waterfall. The stones are

into his picture,—of the plants which spring from their crevices or grow at their base, and of those flowers in their native grace and beauty, which hitherto he has either drawn from recollection, or copied from the formal representations of the botanist.

In addition to their correctness as true representations of natural forms, photographs have a peculiar value, for which no labour or skill on the part of the artist can compensate. In drawing the sketch of a landscape, or delineating the trees, rocks, and foliage which are near him, or the objects in the middle or remote distance, several hours must be spent. During this period, the landscape and its individual parts are undergoing no inconsiderable change. A breeze may disturb the masses of his foliage, and bend his tree stems, and ruffle his verdure, and throw new reflected lights upon the waving crops, while every direct light is changing in intensity and direction during the culmination or descent of the sun. What he has delineated in the morning will hardly correspond with what he draws at noon, and the distances which at one time are finely marked in aerial perspective, will disappear, or even suffer inversion by variations in the intensity and position of the haze. If cottages, or castles, or buildings of any kind, enter into the picture, the shadows of their projections, and the lights upon their walls and roofs will, in sunshine, undergo still greater variations, and the artist will be perplexed with the anachronisms and inconsistencies of *his choicest materials*. The

so exquisitely painted, that nature only could have furnished the originals. We may examine them at a few inches' distance, and recognise forms and structures with which we have been long familiar. A water-ousel, peculiar to Scottish brooks and rivers, perched upon one of them, looks as anxiously around as if a schoolboy were about to avail himself of the missiles at his feet.

landscape thus composed in patches will, in its photograph, have a very different aspect, as much in its forms as in its lights and shadows. The truths of nature are fixed at one instant of time ; the self-delineated landscape is embalmed amid the co-existing events of the physical and social world. If the sun shines, his rays throw their gilding on the picture. If the rain-shower falls, the earth and the trees glisten with its reflexions. If the wind blows, the partially obliterated foliage will display the extent of its agitation. The objects of still life, too, give reality and animation to the scene. The streets display their stationary chariots, the esplanade its military array, and the market-place its colloquial groups, while the fields are studded with the forms and attitudes of animal life. The incidents of time and the forms of space are thus simultaneously recorded, and every picture from the sober palette of the sun becomes an authentic chapter in the history of the world.¹

But, however valuable photography has become to the artist, science has recently given him another important auxiliary. In order to make this available, he must employ a small pocket binocular camera, to take double pictures to be united in the stereoscope. His trees will thus exhibit the roundness of their trunks and stems, the leaves and branches will place themselves at their proper distance, and he will discover the reason of peculiar effects which in the plane photograph he has been unable to understand. Seeing that his own picture is to be upon a plane surface, I can hardly expect to convince the artist that he will obtain more information by reproducing the

¹ These views are well illustrated by the remarkable photographs of the Crimean war.

original in relief. It is a fact, however, beyond dispute, that effects are produced by the stereoscopic union of two plane photographs which are invisible in the single picture. These effects, which are chiefly those of lustre and shade, are peculiarly remarkable in Daguerreotype, and it is by no means easy to explain the cause. In a Daguerreotype, for example, of two figures in black bronze, with a high metallic lustre, it is impossible, by looking at the single picture, to tell the material of which they are made ; but the moment they are united into stereoscopic relief their true character is instantly seen. In a Daguerreotype of Alexander and Bucephalus, portions of the figure seem as if shaded with China ink of a nearly uniform tint, but when seen in relief the peculiar shade entirely disappears. The stereoscopic combination of two surfaces of different intensities, though of the same colour, produces effects which have not yet been sufficiently studied. But, independently of these peculiarities, the artist will certainly derive more aid from his landscape in relief, and from the study of its individual parts, in their roundness and relative distances, than when he examines them in their plane representations. The shadows which the branches of leaves cast upon the trunks and stems of his trees he will be able to trace to the causes which produce them. Effects in outline, as well as in light and shadow, which may perplex him, will find an explanation in the relative distances and differences of apparent magnitude of individual parts ; and, after becoming familiar with his landscape in relief, as it exists in Nature, he cannot fail to acquire new principles and methods of manipulation. Nature flattened upon paper or metal, and Nature round and plump, as if fresh from the chisel of the

Divine sculptor, must teach very different lessons to the aspiring artist.

The historical painter, or the more humble artist who delineates the scenes of common or domestic life, will derive from the photographic camera and the stereoscope advantages of equal importance. The hero, the sage, and the martyr, drawn from living originals, may be placed in the scenes where they suffered, or in the localities which they hallowed. The lawgiver of Egypt, though he exists only in the painter's eye, may take his place beside the giant flanks of Horeb or the awe-inspiring summit of Mount Sinai ; and He whom we may not name may challenge our love and admiration amid the sun-painted scenes of his youth, of his miracles, and of his humiliation. The fragments of ancient grandeur which time and war have spared, the relics of bygone ages which have resisted the destructive elements, will, as the materials of art, give reality and truth to the pictorial history of times past, while the painter of modern events can command the most accurate representations not only of the costume, but of the very persons of the great men whose deeds he is called upon to immortalize. The heroes of the Crimean war, whether friends or foes, will be descried in the trenches in which they fought, amid the ranks which they led to victory, or among the wrecks of the fatal encounter in which they fell. The sun will thus become the historiographer of the future, and in the fidelity of his pencil and the accuracy of his chronicle, truth itself will be embalmed and history cease to be fabulous.

But even in the narrower, though not less hallowed sphere of domestic life, where the magic names of kindred

and home are inscribed, the realities of stereoscopic photography will excite the most thrilling interest. In the transition forms of his offspring, which link infancy with manhood, the parent will recognise the progress of his mortal career, and in the successive phases which mark the sunset of life, the stripling in his turn will read the lesson that his pilgrimage too has a term which must close. Nor are such delineations interesting only as works of art, or as incentives to virtue ; they are instinct with associations vivid and endearing. The picture is connected with its original by sensibilities peculiarly tender. It was the very light which radiated from her brow,—the identical gleam which lighted up her eye,—the hectic flush or the pallid hue that hung upon her cheek, which pencilled the cherished image, and fixed themselves for ever there.

CHAPTER XI.

APPLICATION OF THE STEREOSCOPE TO SCULPTURE,
ARCHITECTURE, AND ENGINEERING.

To the arts of sculpture and architecture, the processes of binocular photography and stereoscopic combination are particularly applicable. The landscape painter has every day within his reach examples of the picturesque, the wild and the sublime in nature. In the fields which surround him, in the river, or even in the "brook that bubbles by," on the shore, on the heath, or on the mountain side, he has the choice of materials for every department of his art. The sculptor has no such advantage. Swathed in impenetrable drapery the human figure mocks his eager eye, and it is only by stolen glances, or during angel visits, few and far between, that he can see those divine forms which it is his business to portray. He must therefore quit his home and seek for the models of ancient and modern art. In the British Museum, in the Louvre, in the Vatican, and in the repositories of art in Berlin, Munich, and other European cities, he must spend months and years in the study of his profession. He must copy, day after day, those master triumphs of genius which the taste of ages has consecrated,

and gather from their study the true principles of his art. Transferred to his own studio, these copies will be his instructor and his guide. They will exhibit to him forms more than human, though human still, embodying all that is true and beautiful in what might be man. The value of these copies, however, depends on the skill and care with which they have been taken ; but no labour however great, and no power of drawing however masterly, can give even an approximate idea either of the outline or round of solid figures, whether single or in groups. Light and shade can alone evolve those muscular prominences, or those soft and sphere-like relievos which give such power and beauty to forms, male and female ; but how can an artist catch and fix those lights and shades which give relief to the parts which they illuminate or obscure ? The light of the sun, even in a cloudless sky, is ever varying in intensity, and the breadth and direction of the shadows which he casts are varying from hour to hour. In a cloudy day, the motion of the clouds, and the varying reflexions within his apartment, subject the lights and shadows to constant change. The portions of the drawing executed in the morning will not harmonize with what is drawn at noon, or during the decline of day. We consider it, therefore, impossible to execute a drawing of a statue, or of a group of statues, from which the artist can have anything like an accurate idea of the forms which compose them.

From all these difficulties the sculptor has been relieved by the invention of the photographic process. He may thus take copies of statues in a few minutes, and take them in all their aspects, and as seen at various distances, and in this manner he will obtain drawings with the shadows as

they existed at a particular instant, so that the lights and shades, upon every individual part of the statue, will be correctly related to each other. But valuable as these drawings are, compared with those executed by the pencil, their value becomes tenfold greater when they are taken with the binocular camera, and with small lenses, as already described. When combined in the stereoscope, he may reproduce the statue in relief, in all its aspects, and of different sizes, and derive from its study the same advantages which the statue itself would have furnished. In one respect the creations of the stereoscope surpass the original. While the artist is surveying and drawing instruction from the marble prototype, its lights and shadows, and consequently the delicate forms, convex and concave, by which they are produced, are constantly changing, whereas, in the stereoscopic statue, everything is fixed and invariable.¹ In taking busts and statues from the living subject, the sculptor will derive great advantage from the stereoscope. Double pictures of the whole, or of any portion of the subject, may be taken and raised into relief, and from such binocular pictures, executed on one side of the globe, an artist, on the other side, may complete an admirable statue. The dying and the dead may thus be modelled without the rude contact of a mask, and those noble forms perpetuated which affection or gratitude has endeared.

We must warn the sculptor, however, against the employment of binocular pictures taken with large lenses. Not only will the individual picture be deformed, but a double

¹ A French sculptor has actually modelled a statue from the stereoscopic relief of binocular pictures.

deformity will be induced by their union ; and whether he copies from a statue or from a living figure, his work must be defective, even to an ordinary eye.

In architecture, and all those arts in which ornamental forms are given to solid materials, the binocular camera and the stereoscope will be found indispensable. The carvings of ancient, or mediæval, or modern art may be copied and reproduced in relief, whatever be the material from which they have been cut. The rich forms of Gothic architecture, and the more classical productions of Greek and Roman genius, will swell the artist's portfolio, and possess all the value of casts. With the aid of the Kaleidoscope the modern artist may surpass all his predecessors. He may create an infinite variety of those forms of symmetry which enter so largely into the decorative arts ; and if the individual forms, which constitute the symmetrical picture, are themselves solid, the binocular-kaleidoscopic pictures, taken photographically, will be raised into the original relief of their component parts, or they may be represented directly to the eye in relief, by semi-lenses placed at the ocular extremities of the reflecting plates.¹ If the symmetrical forms are taken from lines in the same plane, no relief will be obtained from the kaleidoscopic pictures.

But it is not merely to the decorative parts of architecture that the stereoscope is applicable. The noblest edifices, whether of a civil, a religious, or a military character, which he could otherwise study only as a traveller, and represent in hurried and imperfect sketches, will, when taken binocularly, stand before him in their full relief and gran-

¹ See my Treatise on the Kaleidoscope, second edition, just published.

deur, reflecting to his eye the very lights and shadows which at a given hour the sun cast upon their walls.

In the erection of public buildings, hourly or daily photographs have been taken of them, to shew to the absent superintendent the progress of his work ; but these pictures will be still more expressive if binocular ones are combined in the stereoscope.

To the engineer and the mechanist, and the makers of instruments of all kinds, the stereoscope will be of inestimable value. The difficulty of representing machinery is so great that it is not easy to understand its construction or its mode of operation from plans and perspective views of it. The union of one or two binocular pictures of it, when thrown into relief, will, in many cases, remove the difficulty both of drawing and understanding it. Photographs of machinery, however, consisting of a number of minute parts at different distances from the eye, have, when taken by large lenses, all the defects which we explained in reference to trees and their branches and leaves. Supports and axles will be transparent, and the teeth of the wheels, and the small and distant parts of the mechanism, will be seen through all the nearer parts whose width is less than the diameter of the lens.

In taking a binocular picture of a machine or instrument consisting of various parts, that minute accuracy which is necessary to give the true form and expression of the human face is not required ; but if it should happen that, in a correct binocular view of the object, parts are concealed which it would be useful to see, we must discover the binocular angle which will shew these parts in

the two pictures, or, generally speaking, which will give the best view of the mechanism, and then adjust the lenses of the camera to give the desired representations of it. These observations will be found useful in obtaining stereoscopic views of the structures in carpentry and ship-building.

CHAPTER XII.

APPLICATION OF THE STEREOSCOPE TO NATURAL
HISTORY.

IN treating of those objects of natural history which enter into the composition of landscape scenery, such as trees, plants, and rocks, we have pointed out the method of having them accurately drawn for the stereoscope ; but it is to the importance of stereoscopic photography in natural history as a science that we propose to devote the present Chapter.

When we reflect upon the vast number of species which have been described by zoologists, the noble forms of animated nature, whether wild or domesticated, and the valuable services which many of them perform as the slaves of man, we can hardly attach too much importance to the advantage of having them accurately delineated and raised into stereoscopic relief. The animal painters of the present day,—the Landseers, the Cowpers, and the Ansdells, have brought this branch of their art to a high degree of perfection, but the subjects of their pencil have been principally dogs, horses, deer, and cattle, and a few other animals, with which they are well acquainted, and specimens of which were within their reach. To give

accurate representations of giraffes, hyænas, and the rarer animals which are found alive only in zoological gardens and travelling caravans, is a more difficult task, and one which has been necessarily intrusted to inferior hands. In this branch of his art the photographer is perplexed with the difficulty of arresting his subject in a position of repose and in the attitude which he requires. But this difficulty will diminish as his materials become more sensitive to light ; and means may be found for fixing, without constraint, certain animals in the desired position. We have seen the portrait of a dog taken with such minute accuracy that the slightest trace of any motion could not be perceived. Its master directed his attention to a piece of bread, and he stood firmly waiting for his reward. Considering truth as an essential element in all photographs, we are unwilling to counsel the artist to have recourse to a large lens for the purpose of accelerating his process by seizing his restless object in a single instant of time ; but what cannot be tolerated in the human form may be permitted in animal portraiture as a necessary evil. The divine lineaments and delicate forms which in man the intellect and the affections conspire to mould, are concealed under the shaggy drapery of the world of instinct ; and even if they existed and were perceived, could hardly be appreciated by those who have not studied its manners and submitted to its laws. But even in the present state of photography such a celerity of process has been attained that a distinguished amateur in Edinburgh has constructed a portable camera, which, by pulling a trigger, instantaneously records upon its sensitive retina the surf which is hurrying to the shore, or the stranger who is passing in the

street. With such an instrument, in such hands, the denizens of the jungle or of the plains may be taken captive in their finest attitudes and in their most restless moods. Photographs thus obtained will possess a value of no ordinary kind, and when taken in the binocular camera and raised into relief by the stereoscope, will be valuable auxiliaries to the naturalist, and even to the painters and the poets whose works or whose lyrics may require an introduction to the brutes that perish.

In representing with accuracy the osteology and integuments of the zoological world—the framework which protects life, and to which life gives activity and power, the aid of the stereoscope is indispensable. The repose of death, and the sharp pencil which resides in the small lens, will place before the student's eye the skeleton, clothed or unclothed, in accurate perspective and true relief, while he contemplates with wonder, in their true apparent magnitude, the gigantic Mastodon, the colossal Megatherion, and the huge Dinornis, or examines the crushed remains of the lengthened Saurian, or the hollow footsteps which ancient life has impressed on the massive sandstone or the indurated clay.

In the other branches of natural history, ichthyology, ornithology, conchology, &c., the stereoscope will be found equally useful. In entomology, where insects are to be represented, the microscopic binocular camera must be used; and in order to prevent the legs, the antennæ, and other small parts of the object from being transparent, and therefore spotted, with the images of objects or parts beyond them, as explained in a preceding chapter, the smallest lenses should be employed.

The roots and bulbs which are raised by the agriculturist and the horticulturist, the turnip, the beet, the carrot, and the onion ; and the fruits raised in the orchard, on the wall, or in the hothouse, may be exhibited in all their roundness and solidity in the stereoscope ; and as articles of commerce they might be purchased on the authority of their pictures in relief. The microscopic stereoscope will, in like manner, give accurate magnified representations in relief of grains and seeds of all kinds, and by comparing these with the representations of those of a standard form and quality, the purchaser may be enabled to form a better idea of their excellence than if he saw them with his own eyes, or had them in his own hands.

CHAPTER XIII.

APPLICATION OF THE STEREOSCOPE TO EDUCATIONAL
PURPOSES.

THE observations contained in the preceding chapters prepare us for appreciating the value of the stereoscope as an indispensable auxiliary in elementary as well as in professional education. When the scholar has learned to read, to write, and to count, he has obtained only the tools of instruction. To acquire a general knowledge of the works of God and of man—of things common and uncommon—of the miracles of nature and of art, is the first step in the education of the people. Without such knowledge, the humblest of our race is unfit for any place in the social scale. He may have learned to read his Bible, and he may have read it after he had learned to read ;—he may have committed to memory every sentence in the Decalogue ;—he may have packed into the storehouse of his brain all the wisdom of Solomon, and all the divine precepts of a greater than Solomon, while he is utterly ignorant of everything above him, around him, and within him,—ignorant, too, of the form, the magnitude, and the motions of his terrestrial home,—ignorant of the gigantic structures which constitute the material universe,—ignorant of the fabrics which industry prepares for his use, and of the luxuries which com-

merce brings from the ends of the earth and places at his door,—ignorant even of the wonderful operations of that beneficent commissariat, which is every moment, while he sleeps and dreams, elaborating the materials by which he is fed and clothed.

Were we to say, though we do not say it, that in our own country the teachers, so penuriously endowed by the State, are not much in advance of their pupils, we should err only in stating what is not universally true ; and yet there are men of influence and character insisting upon the imposition of sectarian tests, and thus barricading our schools against the admission of the wisest and the fittest masters ! And while every civilized community in the world is eagerly teaching their people, irrespective of religious creeds, the same bigots, civil and ecclesiastical, in our own country, have combined to resist the only system of education which can stem the tide of vice and crime which is desolating the land.

Missionary labour and reformatory institutions, valuable as they are, presuppose an educated community. To instruct and reform a race that can neither read their Bible nor derive knowledge from books, is a task beyond human achievement. The dearest interests of society, therefore, call loudly for *Secular Education*,—the greatest boon which philanthropy ever demanded from the State. The minister who, in the face of sectarian factions, dares not identify himself with a large legislative measure for the education of the people, and resigns office when he fails to carry it, prefers power to duty, and, if he ever possessed it, divests himself of the character of a statesman and a patriot. He may be justified in punishing the law-breaker who cannot read his

statutes, but he is himself the breaker of laws of a higher order, and sanctioned by a higher tribunal.

If the education of the people is to be attempted either by partial or comprehensive legislation, the existing system is utterly inefficient. The teacher, however wisely chosen and well qualified, has not at his command the means of imparting knowledge. He may pour it in by the ear, or extract it from the printed page, or exhibit it in caricature in the miserable embellishments of the school-book, but unless he teaches through the eye, the great instrument of knowledge, by means of truthful pictures, or instruments, or models, or by the direct exhibition of the products of nature and of art, which can be submitted to the scrutiny of the senses, no satisfactory instruction can be conveyed.¹ Every school, indeed, should have a museum, however limited and humble. Even from within its narrow sphere objects of natural history and antiquities might be collected, and duplicates exchanged; and we are sure that many a chimney-piece in the district would surrender a tithe of its curiosities for the public use. Were the British Museum, and other overflowing collections, to distribute among provincial museums the numerous duplicates which they possess, they would gradually pass into the schools, and before a quarter of a century elapsed, museums would be found in every proper locality.

As we cannot indulge in the hope that any such boon

¹ "The importance of establishing a *permanent Museum of Education* in this country, with the view of *introducing improvements in the existing methods of instruction*, and specially directing public attention in a practical manner to the question of National Education, has been of late generally recognised."—*Third Report of the Commissioners for the Exhibition of 1851*, presented to both Houses of Parliament, p. 37. Lond., 1856.

will be conferred on our educational institutions, it becomes an important question how far it is possible to supply the defect by the means within our reach. The photographic process may be advantageously employed in producing accurate representations of those objects, both of nature and of art, which it would be desirable to describe and explain in the instruction of youth; but as experience has not yet taught us that such pictures will be permanent, and capable of resisting the action of time and the elements, it would be hazardous to employ them in the illustration of popular works. It is fortunate, however, that the new art of galvanography enables us, by a cheap process, to give to photographs the permanence of engravings, and to employ them in the illustration of educational works.¹

But however much we may value such an auxiliary, representations or drawings, on a plane, of solids or combinations of solids at different distances from the eye, are in many cases unintelligible even to persons well informed; so that, on this ground alone, we cannot but appreciate the advantages to be derived from binocular pictures and their stereoscopic relief, not only in the instruction of youth, but in the diffusion of knowledge among all ranks of society.

One of the most palpable advantages to be derived from the illustration of school-books by pictures in relief, is the communication of correct knowledge of the various objects of natural history. If, as we have already shewn, the naturalist derives important assistance in his studies from

¹ This fine invention we owe to Mr. Paul Pretsch, late director of the Imperial Printing Office at Vienna. It is secured by patent, and is now in practical operation in Holloway Place, Islington.

correct representations of animated nature, how much more valuable must they be to the scholar who never saw, and may never see the objects themselves. In the department of zoology, the picture might frequently be taken from the living animal, standing before the camera in vigorous life and transcendent beauty ; or when this cannot be done, from the fine specimens of zoological forms which adorn our metropolitan and provincial museums. The trees and plants, too, of distant zones, whether naked in their osteology, or luxurious in their foliage, would shew themselves in full relief ;—the banyan, clinging with its hundred roots to the ground,—the bread-fruit tree, with its beneficent burden,—the cow tree, with its wholesome beverage,—the caoutchouc tree, yielding its valuable juice,—or the deadly upas, preparing its poison for the arrow of the savage or the poniard of the assassin.

With no less interest will the schoolboy gaze on the forms of insect life, which will almost flutter before him, and on the tenants of the air and of the ocean, defective only in the colours which adorn them. The structures of the inorganic world will equally command his admiration. The minerals which have grown in the earth beneath his feet, and the crystals which chemistry has conjured into being, will display to him their geometric forms, infinite in variety, and interesting from their rarity and value. Painted by the very light which streamed from them, he will see, in their retiring and advancing facets, the Kohinoor and other diamonds, and the huge rubies, and sapphires, and emeralds, which have adorned the chaplet of beauty, or sparkled in the diadem of kings. The gigantic productions of the earth will appeal to him with equal power,—the

colossal granites, which have travelled in chariots of ice, and the rounded boulders, which have been transported in torrents of mud; and while he admires, in their strong relief, the precipices of ancient lava—the Doric colonnades of basalt—the upheaved and contorted strata beside them, and the undisturbed beds which no internal convulsions have shaken, he will stand appalled before the fossil giants of the primeval world that trod the earth during its preparation for man, and have been embalmed in stone to instruct and to humble him.

In acquiring a knowledge of physical geography, in which the grander aspects of nature arrest our attention, their stereoscopic representations will be particularly instructive. The mountain range, whether abrupt in its elevation, or retiring from our view,—whether scarred with peaks or undulating in outline,—the insulated mountain tipped with snow or glowing with fire,—the volcano ejecting its burning missiles,¹—the iceberg fixed in the shore, or floating on the deep,—the deafening cataract,—the glacier and its moraines, sinking gently to the plains,—and even the colossal wave with its foaming crest, will be portrayed in the binocular camera, and exhibited in all the grandeur and life of nature.

The works of human hands,—the structures of civilisation, will stand before the historian and the antiquary, as

¹ An accomplished traveller, the Rev. Mr. Bridges, who ascended Mount Etna for the purpose of taking Talbotype drawings of its scenery, placed his camera on the edge of the crater to obtain a representation of it. No sooner was the camera fixed and the sensitive paper introduced, than an eruption took place, which forced Mr. Bridges to quit his camera in order to save his life. When the eruption closed, he returned to collect the fragments of his instrument, when, to his great surprise and delight, he found that his camera was not only uninjured, but contained a picture of the crater and its eruption.

well as the student, in their pristine solidity, or in their ruined grandeur,—the monuments by which sovereigns and nations have sought to perpetuate their names,—the gorgeous palaces of kings,—the garish temples of superstition,—the humbler edifices of Christian faith,—the bastions and strongholds of war, will display themselves in the stereoscope as if the observer were placed at their base, and warmed by the very sun which shone upon their walls.

Although few of our village youth may become sculptors, yet the exhibition of ancient statues in their actual relief, and real apparent magnitude, cannot fail to give them salutary instruction and rational pleasure. To gaze upon the Apollo Belvidere,—the Venus de Medici,—the Laocoon, and the other masterpieces of ancient art, standing in the very halls which they now occupy ; or to see the *chef d'œuvres* of Canova, Thorvaldsen, and Chantrey, or the productions of living artists in their own studio, with the sculptor himself standing by their side, will excite an interest of no ordinary kind.

From the works of the architect, the engineer, and the mechanist, as exhibited in full relief, the student, whether at our schools or colleges, will derive the most valuable instruction. The gigantic aqueducts of ancient and modern times,—the viaducts and bridges which span our valleys and our rivers, and the machinery in our arsenals, factories, and workshops, will be objects of deep interest to the general as well as the professional inquirer.

There is yet another application of the stereoscope to educational purposes, not less important than those which have been mentioned. In the production of diagram

representing instruments and apparatus, which cannot be understood from drawings of them on a plane, it will be of incalculable use to the teacher to have stereoscopic pictures of them. In every branch of physical science, diagrams of this kind are required. When they are intended to represent apparatus and instruments, either for illustrating known truths, or carrying on physical researches, binocular pictures can be easily obtained ; but when the diagrams have not been taken from apparatus, but are merely combinations of lines, we can obtain binocular photographs of them only from models constructed on purpose. These models will give binocular representations in various azimuths, so that the true position of planes at different inclinations, and lines at various angles with each other, and at different distances from the eye, will be readily apprehended. Astronomical diagrams, in which orbits, &c., may be represented by wires, and optical figures, in which the rays may be formed by threads or wires, would be thus easily executed.

Among the binocular diagrams, consisting of white lines upon a black ground, which have been executed in Paris, there is one representing the apparatus in which a ray of light, polarized by reflexion from a glass plate, passes through a crystallized film perpendicular to the plane of the paper, and is subsequently analysed by reflexion from another plate at right angle to the following plate. This diagram, when placed in relief by the stereoscope, gives as correct an idea of the process as the apparatus itself.

As an auxiliary in the investigation of questions of difficulty and importance, both in physics and metaphysics, the stereoscope is peculiarly valuable. It enables us to place

in its true light the celebrated theory of vision on which Bishop Berkeley reared the ideal philosophy, of which he was the founder, and it gives us powerful aid in explaining many physical phenomena which have long baffled the ingenuity of philosophers. It would be out of place to give any account of these in a work like this, but there is one so remarkable, and at the same time so instructive, as to merit special notice. In order to exhibit, by means of *three* diagrams, a solid in relief and hollow at the same time, which had not been previously done, I executed three drawings of the frustum of a cone, resembling those in Fig. 31, so that the *left-hand* one and the middle one gave the *hollow* cone, while the *middle* one and the *right-hand* one gave the *raised* cone. Having their summits truncated, as in the figure, the cones exhibit, in the one case, a circle at the bottom of the hollow cone, and in the other, a circle on the summit of the raised cone. When these three diagrams¹ are placed in an open lenticular stereoscope, or are united by the convergency of the optical axes, so that we can not only see the *hollow* and the *raised* cones, but the flat drawing on each side of them, we are enabled to give an ocular and experimental proof of the cause of the large size of the horizontal moon, of her small size when in the meridian or at a great altitude, and of her intermediate apparent magnitude at intermediate altitudes,—phenomena which had long perplexed astronomers, and which Dr. Berkeley, rejecting previous and well-founded explanations, ascribed to the different degrees of brightness of the moon in these different positions.

¹ A binocular slide, copied from the one originally designed by myself, forms No. 27 of the Series of white-lined diagrams upon a black ground executed in Paris. The drawings, however, are too large for the common stereoscope.

As the circular summit of the *raised* cone *appears* to be *nearest* the eye of the observer, the summit of the *hollow* cone *farthest* off, and the similar central circle in the flat drawing on each side, at an intermediate distance, the apparent distances from the eye of different and equal circles will represent the apparent distance of the moon in the *zenith*, or very high in the elliptical celestial vault,—the same distance when she is in the *horizon*, and the same when at an intermediate altitude. Being in reality of exactly the same size, and at the same distance from the eye, these circular summits, or sections of the cone, are precisely in the same circumstances as the moon in the three positions already mentioned. If we now contemplate them in the lenticular stereoscope, we shall see the circular summit of the *hollow* cone the *largest*, like the *horizontal* moon, because it *seems* to be at the *greatest* distance from the eye,—the circular summit of the *raised* cone the *smallest*, because it appears at the *least* distance, like the *zenith* or culminating moon,—and the circular summits of the flat cones on each side, of an *intermediate* size, like the moon at an *intermediate* altitude, because their distance from the eye is intermediate. The same effect will be equally well seen by placing three small wafers of the same size and colour on the square summits of the drawings of the quadrangular pyramids, or more simply, by observing the larger size of the square summit of the hollow pyramid.

This explanation of the cause of the increased size of the horizontal moon is rigorously correct. If any person should suspect that the circles which represent the moon are unequal in size, or are at different distances from the eye, they have only to cut the diagram into three parts, and make

each drawing of the frustum of the cone occupy a different place in the binocular slide, and they will obtain the very same results. Hence we place beyond a doubt the incorrectness of Dr. Berkeley's theory of the size of the horizontal moon,—a theory to which the stereoscope enables us to apply another test, for if we make one or more of these circles less bright than the rest, no change whatever will be produced in their apparent magnitude.

CHAPTER XIV.

APPLICATION OF THE STEREOSCOPE TO PURPOSES OF
AMUSEMENT.

EVERY experiment in science, and every instrument depending on scientific principles, when employed for the purpose of amusement, must necessarily be instructive. "Philosophy in sport" never fails to become "Science in earnest." The toy which amuses the child will instruct the sage, and many an eminent discoverer and inventor can trace the pursuits which immortalize them to some experiment or instrument which amused them at school. The soap bubble, the kite, the balloon, the water wheel, the sun-dial, the burning-glass, the magnet, &c., have all been valuable incentives to the study of the sciences.

In a list of about 150 binocular pictures issued by the London Stereoscopic Company, under the title of "Miscellaneous Subjects of the 'Wilkie' character," there are many of an amusing kind, in which scenes in common life are admirably represented. Following out the same idea, the most interesting scenes in our best comedies and tragedies might be represented with the same distinctness and relief as if the actors were on the stage. Events and scenes in ancient and modern history might be similarly exhibited, and in our day, binocular pictures of trials, congresses,

political, legislative, and religious assemblies, in which the leading actors were represented, might be provided for the stereoscope.

For the purpose of amusement, the photographer might carry us even into the regions of the supernatural. His art, as I have elsewhere shewn, enables him to give a spiritual appearance to one or more of his figures, and to exhibit them as "thin air" amid the solid realities of the stereoscopic picture. While a party is engaged with their whist or their gossip, a female figure appears in the midst of them with all the attributes of the supernatural. Her form is transparent, every object or person beyond her being seen in shadowy but distinct outline. She may occupy more than one place in the scene, and different portions of the group might be made to gaze upon one or other of the visions before them. In order to produce such a scene, the parties which are to compose the group must have their portraits nearly finished in the binocular camera, in the attitude which they may be supposed to take, and with the expression which they may be supposed to assume, if the vision were real. When the party have nearly sat the proper length of time, the female figure, suitably attired, walks quickly into the place assigned her, and after standing a few seconds in the proper attitude, retires quickly, or takes as quickly, a second or even a third place in the picture if it is required, in each of which she remains a few seconds, so that her picture in these different positions may be taken with sufficient distinctness in the negative photograph. If this operation has been well performed, all the objects immediately behind the female figure, having been, previous to her introduction,

impressed upon the negative surface, will be seen through her, and she will have the appearance of an aerial personage, unlike the other figures in the picture. This experiment may be varied in many ways. One body may be placed within another, a chicken, for example, within an egg, and singular effects produced by combining plane pictures with solid bodies in the arrangement of the persons and things placed before the binocular camera. Any individual in a group may appear more than once in the same picture, either in two or more characters, and no difficulty will be experienced by the ingenious photographer in giving to these double or triple portraits, when it is required, the same appearance as that of the other parties who have not changed their place. In groups of this kind curious effects might be produced by placing a second binocular slide between the principal slide and the eye, and giving it a motion within the stereoscope. The figures upon it must be delineated photographically upon a plate of glass, through which the figures on the principal slide are seen, and the secondary slide must be so close to the other that the figures on both may be distinctly visible, if distinct vision is required for those which are to move.

Another method of making solid figures transparent in a photograph has been referred to in the preceding chapter, and may be employed in producing amusing combinations. The transparency is, in this case, produced by using a large lens, the margin of which receives the rays which issue from bodies, or parts of bodies, situated *behind* other bodies, or parts of bodies, whose images are given in the photograph. The body thus rendered transparent must be less in superficial extent than the lens, and the body seen through it must be so far

behind it that rays emanating from it would fall upon some part of the lens, the luminosity of this body on the photograph being proportional to the part of the surface of the lens upon which the rays fall. This will be readily understood from Figs. 48 and 49, and their description, and the ingenious photographer will have no difficulty in producing very curious effects from this property of large object-glasses.

One of the most interesting applications of the stereoscope is in combining binocular pictures, constructed like the plane picture, used in what has been called the *cosmorama* for exhibiting dissolving views. These plane pictures are so constructed, that when we view them by reflected light, as pictures are generally viewed, we see a particular scene, such as the Chamber of Deputies in its external aspect ; but when we allow no light to fall upon it, but view it by transmitted light, we see the interior of the building brilliantly lighted up, and the deputies listening to the debate. In like manner, the one picture may represent two armies in battle array, while the other may represent them in action. A cathedral in all its architectural beauty may be combined with the same building in the act of being burned to the ground ; or a winter scene covered with snow may be conjoined with a landscape glowing with the warmth and verdure of summer. In the cosmorama, the reflected light which falls upon the front of the one picture is obtained by opening a lid similar to that of the stereoscope, as shewn at CD, Fig. 14, while another lid opening behind the picture stops any light which might pass through it, and prevents the second picture from being seen. If, when the first picture is visible, we gradually open the lid behind it, and close the lid CD before it, it

gradually disappears, or *dissolves*, and the second picture gradually appears till the first vanishes and the second occupies its place. A great deal of ingenuity is displayed by the Parisian artists in the composition of these pictures, and the exhibition of them, either in small portable instruments held in the hand, or placed on the table, or on a great scale, to an audience, by means of the oxygen and hydrogen light, never fails to excite admiration.

The pictures thus exhibited, though finely executed, have only that degree of relief which I have called *monocular*, and which depends on correct shading and perspective ; but when the dissolving views are obtained from binocular pictures, and have all the high relief given them by their stereoscopic combination, the effect must be singularly fine.

Very interesting and amusing effects are produced by interchanging the right and the left eye pictures in the stereoscope. In general, what was formerly convex is now concave, what was round is hollow, and what was near is distant. The effect of this interchange is finely seen in the symmetrical diagrams, consisting of white lines upon black ground, such as Nos. 1, 5, 9, 12, 18 and 27 of the Parisian set ; but when the diagrams are not symmetrical, that is, when the one half is not the reflected image of the other, such as Nos. 26, &c., which are transparent polygonal solids, formed as it were by white threads or wires, no effect, beyond a slight fluttering, is perceived. As the right and left eye pictures are inseparable when on glass or silver plate, the experiments must be made by cutting in two the slides on Bristol board. This, however, is unnecessary when we have the power of uniting the two pictures by the

convergency of the optic axes to a nearer point, as we obtain, in this case, the same effect as if we had interchanged the pictures. The following are some of the results obtained in this manner from well-known slides :—

In single portraits no effect is produced by the interchange of the right and left eye pictures. If any loose part of the dress is in the foreground it may be carried into the distance, and *vice versa*. In one portrait, the end of the hat-band, which hung down loosely behind the party, was made to hang in front of it.

In pictures of streets or valleys, and other objects in which the foreground is connected with the middle-ground, and the middle-ground with the distance, without any break, no effect is produced by the interchange. Sometimes there is a little bulging out of the middle distance, injurious to the monocular effect.

In the binocular picture of the Bridge of Handeck, the Chalet in the foreground retires, and the middle distance above it advances.

In the picture of the sacristy of Notre Dame, the sacristy retires within the cathedral.

In the Maison des Chapiteaux at Pompeii, the picture is completely inverted, the objects in the distance coming into the foreground.

In the Daguerreotype of the Crystal Palace, the water in the foreground, with the floating plants, retires and takes an inclined position below a horizontal plane.

In the binocular picture of the lower glacier of Rosenlauri, the roof of the ice-cave becomes hollow, and the whole foreground is thrown into a disordered perspective.

In Copeland's Venus, the arm holding the bunch of

grapes is curiously bent and thrown behind the head, while the left arm advances before the child.

In the picture of the Greek Court in the Crystal Palace, the wall behind the statues and columns advances in front of them.

The singular fallacy in vision which thus takes place is best seen in a picture where a number of separate articles are placed upon a table, and in other cases where the judgment of the spectator is not called upon to resist the optical effect. Although the nose of the human face should retire behind the ears yet no such effect is produced, as all the features of the face are connected with each other, but if the nose and ears had been represented separately in the position which they occupy in the human head, the nearer features would have retired behind the more remote ones, like the separate articles on a table.

We shall have occasion to resume this subject in our concluding chapter on the fallacies which take place in viewing solids, whether raised or hollow, and whether seen by direct or inverted vision.

CHAPTER XV.

ON THE PRODUCTION OF STEREOSCOPIC PICTURES FROM
A SINGLE PICTURE.

THOSE who are desirous of having stereoscopic *relievos* of absent or deceased friends, and who possess single photographic portraits of them, or even oil paintings or miniatures, will be anxious to know whether or not it is possible to obtain from one plane picture another which could be combined with it in the stereoscope ; that is, if we consider the picture as one seen by either eye alone, can we by any process obtain a second picture as seen by the other eye ? We have no hesitation in saying that it is impossible to do this by any direct process.

Every picture, whether taken photographically or by the eye, is necessarily a picture seen by one eye, or from one point of sight ; and, therefore, a skilful artist, who fully understands the principle of the stereoscope, might make a copy of any picture as seen by the other eye, so approximately correct as to appear in relief when united with the original in the stereoscope ; but the task would be a very difficult one, and if well executed, so as to give a *relievo* without distortion, the fortune of the painter would be made.

When the artist executes a portrait, he does it from one point of sight, which we may suppose fixed, and corresponding with that which is seen with his *left* eye. If he takes another portrait of the same person, occupying exactly the same position, from another point of sight, two and a half inches to the right of himself, as seen with his *right* eye, the two pictures will differ only in this, that each point in the head, and bust, and drapery, will, in the second picture, *be carried farther to the left of the artist on the plane of representation.* The points which project most, or are most distant from that plane, will be carried farther to the left than those which project less, the extent to which they are carried being proportional to the amount of their projection, or their distance from the plane. But since the painter cannot discover from the original or left-eye plane picture the degree of prominence of the leading points of the head, the bust, and the drapery, he must work by guess, and submit his empirical touches, step by step, to the judgment of the stereoscope. In devoting himself to this branch of the art he will doubtless acquire much knowledge and dexterity from experience, and may succeed to a very considerable extent in obtaining pictures in relief, if he follows certain rules, which we shall endeavour to explain.

If the given portrait, or picture of any kind, is not of the proper size for the stereoscope, it must be reduced to that size, by taking a photographic copy of it, from which the right-eye picture is to be drawn.

In order to diminish the size of the diagram, let us suppose that the plane on which the portrait is taken touches the back of the head, and is represented in section

by AB , Fig. 50. We must now assume, under the guidance of the original, a certain form of the head, whose breadth from ear to ear is EE'' , N being the point of the

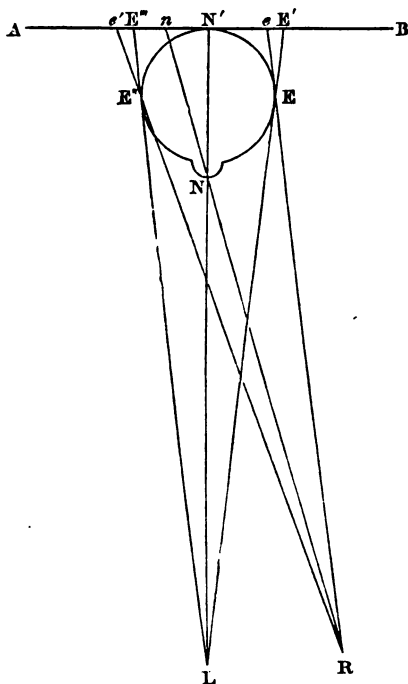


FIG. 50.

nose in the horizontal section of the head, $E''NEN'$, passing through the nose N , and the lobes EE'' of the two ears. Let L, R be the left and right eyes of the person viewing them, and LN the distance at which they are viewed, and

let lines be drawn from L and R, through L, N, E and E', meeting the plane AB on which the portrait is taken in e , E'' , n , N' , e , and E' . The breadth, $E''e$, and the distances of the nose from the ears $N'E'$, $N'E''$, being given by measurement of the photograph suited to the stereoscope, the distances NN' , EE' , $E'E''$ may be approximately obtained from the known form of the human head, either by projection or calculation. With these data, procured as correctly as we can, we shall, from the position of the nose n , as seen by the right eye R, have the formula

$$N'n = \frac{LR \times NN'}{NL}.$$

The distance of the *right* ear e' , from the right-eye picture, will be,

$$ne' = e'N - N'n; \text{ and as } E'e = \frac{LR \times EE'}{EL}.$$

The distance of the *left* ear e , in the right-eye picture, from the nose n , will be

$$ne = N'n + N'E' - E'e.$$

In order to simplify the diagram we have made the original, or left-eye picture, a front view, in which the nose is in the middle of the face, and the line joining the ears parallel to the plane of the picture.

When the position of the nose and the ears has been thus approximately obtained, the artist may, in like manner, determine the place of the pupils of the two eyes, the point of the chin, the summit of the eyebrows, the prominence of the lips, and the junction of the nose with the teeth, by assuming, under the guidance of the original picture, the distance of these different parts from the plane of projection. In the same way other leading points in the figure and drapery may be found, and if these points are deter-

mined with tolerable accuracy the artist will be able to draw the features in their new place with such correctness as to give a good result in the stereoscope.

In drawing the right-eye picture the artist will, of course, employ as the groundwork of it a faint photographic impression of the original, or left-eye picture, and he may, perhaps, derive some advantage from placing the original, when before the camera, at such an inclination to the axis of the lens as will produce the same diminution in the horizontal distance between any two points in the head, at a mean distance between N and N' , as projected upon the plane AB . The line $N'E''$, for example, which in the left-eye photograph is a representation of the cheek NE' , is reduced, in the right-eye photograph, to ne' , and, therefore, if the photograph on AB , as seen by the right eye, were placed so obliquely to the axis of the lens that $N'e$ was reduced to ne' , the copy obtained in the camera would have an approximate resemblance to the right-eye picture required, and might be a better groundwork for the right-eye picture than an accurate copy of the photograph on AB , taken when it is perpendicular to the axis of the lens.

In preparing the right-eye picture, the artist, in place of using paint, might use very dilute solutions of aceto-nitrate of silver, beginning with the faintest tint, and darkening these with light till he obtained the desired effect, and, when necessary, diminishing the shades with solutions of the hypo-sulphite of soda. When the picture is finished, and found satisfactory, after examining its relief in the stereoscope, a negative picture of it should be obtained in the camera, and positive copies taken, to form, with the original photographs, the pair of binocular portraits required.

CHAPTER XVI.

ON CERTAIN FALLACIES OF SIGHT IN THE VISION OF
SOLID BODIES.

IN a preceding chapter I have explained a remarkable fallacy of sight which takes place in the stereoscope when we interchange the binocular pictures, that is, when we place the right-eye picture on the left side, and the left-eye picture on the right side. The objects in the foreground of the picture are thus thrown into the background, and, *vice versa*, the same effect, as we have seen, takes place when we unite the binocular pictures, in their usual position, by the ocular stereoscope, that is, by converging the optic axes to a point between the eye and the pictures. In both these cases the objects are only the plane representations of solid bodies, and the change which is produced by their union is not in their form but in their position. In certain cases, however, when the object is of some magnitude in the picture, the form is also changed in consequence of the inverse position of its parts. That is, the drawings of objects that are naturally convex will appear concave, and those which are naturally concave will appear convex.

In these phenomena there is no mental illusion in their production. The two similar points in each picture, if they are nearer to one another than other two similar

points, must, in conformity with the laws of vision, appear nearer the eye when combined in the common stereoscope. When this change of place and form does not appear, as in the case of the human figure, previously explained, it is by a mental illusion that the law of vision is controlled.

The phenomena which we are about to describe are, in several respects, different from those to which we have referred. They are seen in *monocular* as well as in *binocular* vision, and they are produced in all cases under a mental illusion, arising either from causes over which we have no control, or voluntarily created and maintained by the observer. The first notice of this class of optical illusion was given by Aguilonius in his work on optics, to which we have already had occasion to refer.¹ After proving that convex and concave surfaces appear plane when seen at a considerable distance, he shews that the same surfaces, when seen at a moderate distance, frequently appear what he calls *converse*, that is, the concave convex, and the convex concave. This conversion of forms, he says, is often seen in the globes or balls which are fixed on the walls of fortifications, and he ascribes the phenomena to the circumstance of the mind being imposed upon from not knowing in what direction the light falls upon the body. He states that a concavity differs from a convexity only in this respect, that if the shadow is on the same side as that from which the light comes it is a concavity, and if it is on the opposite side, it is a convexity. Aguilonius observes also, that in pictures imitating nature, a similar mistake is committed as to the form of surfaces. He supposes that a circle is drawn upon a table and shaded on one side so as

¹ See Chap. I. p. 15.

to represent a convex or a concave surface. When this shaded circle is seen at a great distance, it appears a plane surface, notwithstanding the shadow on one side of it ; but when we view it at a short distance, and suppose the light to come from the same side of it as the part not in shadow, the plane circle will appear to be a convexity, and if we suppose the light to come from the same side as the shaded part, the circle will appear to be a concavity.

More than half a century after the time of Aguilonius, a member of the Royal Society of London, at one of the meetings of that body, when looking at a guinea through a compound microscope which inverted the object, was surprised to see the head upon the coin depressed, while other members were not subject to this illusion.

Dr. Philip Gmelin¹ of Wurtemberg, having learned from a friend, that when a common seal is viewed through a compound microscope, the depressed part of the seal appeared elevated, and the elevated part depressed, obtained the same result, and found, as Aguilonius did, that the effect was owing to the inversion of the shadow by the microscope. One person often saw the phenomena and another did not, and no effect was produced when a raised object was so placed between two windows as to be illuminated on all sides.

In 1780 Mr. Rittenhouse, an American writer, repeated these experiments with an inverting eye-tube, consisting of two lenses placed at a distance greater than the sum of their focal lengths, and he found that when a reflected light was thrown on a cavity, in a direction opposite to that of the light which came from his window, the cavity was

¹ *Phil. Trans.* 1744.

raised into an elevation by looking through a tube without any lens. In this experiment the shadow was inverted, just as if he had looked through his inverting eye-tube.

In studying this subject I observed a number of singular phenomena, which I have described in my *Letters on Natural Magic*,¹ but as they were not seen by binocular vision I shall mention only some of the more important facts. If we take one of the intaglio moulds used by the late Mr. Henning for his bas-reliefs, and direct the eye to it steadily, without noticing surrounding objects, we may distinctly see it as a bas-relief. After a little practice I have succeeded in raising a complete hollow mask of the human face, the size of life, into a projecting head. This result is very surprising to those who succeed in the experiment, and it will no doubt be regarded by the sculptor who can use it as an auxiliary in his art.

Till within the last few years, no phenomenon of this kind, either as seen with one or with two eyes, had been noticed by the casual observer. Philosophers alone had been subject to the illusion, or had subjected others to its influence. The following case, however, which occurred to Lady Georgiana Wolff, possesses much interest, as it could not possibly have been produced by any voluntary effort. "Lady Georgiana," says Dr. Joseph Wolff in his *Journal*, "observed a curious optical deception in the sand, about the middle of the day, when the sun was strong: *all the foot-prints, and other marks that are indented in the sand, had the appearance of being raised out of it.* At these times there was such a glare, that it was unpleasant for the

¹ *Letter v.* pp. 98-107. See also the *Edinburgh Journal of Science*, Jan. 1826, vol. iv. p. 99.

eye."¹ Having no doubt of the correctness of this observation, I have often endeavoured, though in vain, to witness so remarkable a phenomenon. In walking, however, in the month of March last, with a friend on the beach at St. Andrews, the phenomenon presented itself, at the same instant, to myself and to a lady who was unacquainted with this class of illusions. The impressions of the feet of men and of horses were distinctly raised out of the sand. In a short time they resumed their hollow form, but at different places the phenomenon again presented itself, sometimes to myself, sometimes to the lady, and sometimes to both of us simultaneously. The sun was near the horizon on our left hand, and the white surf of the sea was on our right, strongly reflecting the solar rays. It is very probable that the illusion arose from our considering the light as coming from the white surf, in which case the shadows in the hollow foot-prints were such as could only be produced by foot-prints raised from the sand, as if they were in relief. It is possible that, when the phenomenon was observed by Lady Georgiana Wolff, there may have been some source of direct or reflected light opposite to the sun, or some unusual brightness of the clouds, if there were any in that quarter, which gave rise to the illusion.

When these illusions, whether monocular or binocular, are produced by an inversion of the shadow, either real or supposed, they are instantly dissipated by holding a pin in the field of view, so as to indicate by its shadow the real place of the illuminating body. The figure will appear raised or depressed, according to the knowledge which we obtain of the source of light, by introducing or withdrawing

¹ *Journal*, 1839, p. 189.

the pin. When the inversion is produced by the eye-piece of a telescope, or a compound microscope, in which the field of view is necessarily small, we cannot see the illuminating body and the convex or concave object (the cameo or intaglio) at the same time ; but if we use a small inverting telescope, $1\frac{1}{2}$ or 2 inches long, such as that shewn at MN, Fig. 36, we obtain a large field of view, and may see at the same time the object and a candle placed beside it. In this case the illusion will take place according as the candle is seen beside the object or withdrawn.

If the object is a white tea-cup, or bowl, however large, and if it is illuminated from behind the observer, the reflected image of the window will be in the concave bottom of the tea-cup, and it will not rise into a convexity if the illumination from surrounding objects is uniform ; but if the observer moves a little to one side, so that the reflected image of the window passes from the centre of the cup, then the cup will rise into a convexity, when seen through the inverting telescope, in consequence of the position of the luminous image, which could occupy its place only upon a convex surface. If the concave body were cut out of a piece of chalk, or pure unpolished marble, it would appear neither convex nor concave, but flat.

Very singular illusions take place, both with one and two eyes, when the object, whether concave or convex, is a hollow or an elevation in or upon a limited or extended surface—that is, whether the surface occupies the whole visible field, or only a part of it. If we view, through the inverting telescope or eye-piece, a dimple or a hemispherical cavity in a broad piece of wood laid horizontally on the table, and illuminated by *quaquaversus light*, like that of the sky, it

will instantly rise into an elevation, the end of the telescope or eye-piece resting on the surface of the wood. The change of form is, therefore, not produced by the inversion of the shadow, but by another cause. The surface in which the cavity is made is obviously inverted as well as the cavity, that is, it now looks downward in place of upward ; but it does not appear so to the observer leaning upon the table, and resting the end of his eye-piece upon the wooden surface in which the cavity is made. The surface seems to him to remain where it was, and still to look upwards, in place of looking downwards. If the observer strikes the wooden surface with the end of the eye-piece, this conviction is strengthened, and he believes that it is the lower edge of the field of view, or object-glass, that strikes the apparent wooden surface or rests upon it, whereas the wooden surface has been inverted, and optically separated from the lower edge of the object-glass.

In order to make this plainer, place a pen upon a sheet of paper with the quill end nearest you, and view it through the inverting telescope : The quill end will appear farthest from you, and the paper will not appear inverted. In like manner, the letters on a printed page are inverted, the top of each letter being nearest the observer, while the paper seems to retain its usual place. Now in both these cases the paper is inverted as well as the quill and the letters, and in reality the image of the quill and of the pen, and of the lower end of the letters, is nearest the observer. Let us next place a tea-cup on its side upon the table, with its concavity towards the observer, and view it through the inverting telescope. It will rise into a convexity, the nearer margin of the cup appearing farther off than the bottom.

If we place a short pen within the cup, measuring as it were its depth, and having its quill end nearest the observer, the pen will be inverted, in correspondence with the conversion of the cup into a convexity, the quill end appearing more remote, like the margin of the cup which it touches, and the feather end next the eye like the summit of the convex cup on which it rests.

In these experiments, the conversion of the concavity into a convexity depends on two separate illusions, one of which springs from the other. The *first* illusion is the erroneous conviction that the surface of the table is looking upwards as usual, whereas it is really inverted; and the *second* illusion, which arises from the first, is, that the *nearest* point of the object appears *farthest* from the eye, whereas it is *nearest* to it. All these observations are equally applicable to the vision of convexities, and hence it follows, that the conversion of relief, caused by the use of an inverting eye-piece, is not produced directly by the inversion, but by an illusion arising from the inversion, in virtue of which we believe that the remotest side of the convexity is nearer our eye than the side next us.

In order to demonstrate the correctness of this explanation, let the hemispherical cavity be made in a stripe of wood, narrower than the field of the inverting telescope with which it is viewed. It will then appear really inverted, and free from both the illusions which formerly took place. The thickness of the stripe of wood is now distinctly seen, and the inversion of the surface, which now looks downward, immediately recognised. The edge of the cavity now appears *nearest* the eye, as it really is, and *the concavity, though inverted, still appears a concavity.* The same effect is pro-

duced when a convexity is placed on a narrow stripe of wood.

Some curious phenomena take place when we view, at different degrees of obliquity, a hemispherical cavity raised into a convexity. At every degree of obliquity from 0° to 90° , that is, from a vertical to a horizontal view of it, *the elliptical margin of the convexity will always be visible*, which is impossible in a real convexity, and the elevated apex will gradually sink till the elliptical margin becomes a straight line, and *the imaginary convexity completely levelled*. The struggle between truth and error is here so singular, that while one part of the object has become concave, the other part retains its convexity !

In like manner, when a convexity is seen as a concavity, the concavity loses its true shape as it is viewed more and more obliquely, till its remote elliptical margin is encroached upon, or eclipsed, by the apex of the convexity ; and towards an inclination of 90° the concavity disappears altogether, under circumstances analogous to those already described.

If in place of using an inverting telescope we invert the concavity, by looking at its inverted image in the focus of a convex lens, it will sometimes appear a convexity and sometimes not. In this form of the experiment the image of the concavity, and consequently its apparent depth, is greatly diminished, and therefore any trivial cause, such as a preconception of the mind, or an approximation to a shadow, or a touch of the concavity by the point of the finger, will either produce a conversion of form or dissipate the illusion when it is produced.

In the preceding Chapter we have supposed the con-

vexity to be high and the concavity deep and circular, and we have supposed them also to be shadowless, or illuminated by a *quaquaversus* light, such as that of the sky in the open fields. This was done in order to get rid of all secondary causes which might interfere with and modify the normal cause, when the concavities are shallow, and the convexities low and have distinct shadows, or when the concavity, as in seals, has the shape of an animal or any body which we are accustomed to see in relief.

Let us now suppose that a strong shadow is thrown upon the concavity. In this case the normal experiment is much more perfect and satisfactory. The illusion is complete and invariable when the concavity is in or upon an extended surface, and it as invariably disappears, or rather is not produced, when it is in a narrow stripe.

In the secondary forms of the experiment, the inversion of the shadow becomes the principal cause of the illusion ; but in order that the result may be invariable, or nearly so, the concavities must be shallow and the convexities but slightly raised. At great obliquities, however, this cause of the conversion of form ceases to produce the illusion, and in varying the inclination from 0° to 90° the cessation takes place sooner with deep than with shallow cavities. The reason of this is that the shadow of a concavity is very different at great obliquities from the shadow of a convexity. The shadow never can emerge out of a cavity so as to darken the surface in which the cavity is made, whereas the shadow of a convexity soon extends beyond the outline of its base, and finally throws

a long stripe of darkness over the surface on which it rests. Hence it is impossible to mistake a convexity for a concavity when its shadow extends beyond its base.

When the concavity upon a seal is a horse, or any other animal, it will often rise into a convexity *when seen through a single lens*, which does not invert it ; but the illusion disappears at great obliquities. In this case, the illusion is favoured or produced by two causes ; the first is, that the form of the horse or other animal in relief is the one which the mind is most disposed to seize, and the second is, that we use only one eye, with which we cannot measure depths as well as with two. The illusion, however, still takes place when we employ a lens three or more inches wide, so as to permit the use of both eyes, but it is less certain, as the binocular vision enables us in some degree to keep in check the other causes of illusion.

The influence of these secondary causes is strikingly displayed in the following experiment. In the armorial bearings upon a seal, the shield is often more deeply cut than the surrounding parts. With binocular vision, the shallow parts rise into relief sooner than the shield, and continue so while the shield remains depressed ; but if we shut one eye the shield then rises into relief like the rest. In these experiments with a single lens a slight variation in the position of the seal, or a slight change in the intensity or direction of the illumination, or particular reflexions from the interior of the stone, if it is transparent, will favour or oppose the illusion. In viewing the shield at the deepest portion with a single lens, a slight rotation of the seal round the wrist, backwards and forwards, will

remove the illusion, in consequence of the eye perceiving that the change in the perspective is different from what it ought to be.

In my *Letters on Natural Magic*, I have described several cases of the conversion of form in which inverted vision is not employed. Hollows in mother-of-pearl and other semi-transparent bodies often rise into relief, in consequence of a quantity of light, occasioned by refraction, appearing on the side next the light, where there should have been a shadow in the case of a depression. Similar illusions take place in certain pieces of polished wood, calcedony, mother-of-pearl, and other shells, where the surface is perfectly plane. This arises from there being at that place a knot, or growth, or nodule, differing in transparency from the surrounding mass. The thin edge of the knot, &c., opposite the candle, is illuminated by refracted light, so that it takes the appearance of a concavity. From the same cause arises the appearance of dimples in certain plates of calcedony, which have received the name of *hammered calcedony*, or *agate*, from their having the look of being dimpled with a hammer. The surface on which these cavities are seen contains sections of small spherical formations of siliceous matter, which exhibit the same illusion as the cavities in wood. Mother-of-pearl presents similar phenomena, and so common are they in this substance that it is difficult to find a mother-of-pearl button or counter which seems to have its surface flat, although it is perfectly so when examined by the touch. Owing to the different refractions of the incident light by the different growths of the shell, cut in different directions by the artificial surface, like the annual growth of wood in a

dressed plank, the surface of the mineral has necessarily an unequal and undulating appearance.

In viewing good photographic or well-painted miniature portraits in an erect and inverted position, and with or without a lens, considerable changes take place in the apparent relief. Under ordinary vision there is a certain amount of relief depending upon the excellence of the picture. If we invert the picture, by turning it upside down, the relief is perceptibly increased. If we view it when erect, with a lens of about an inch in focal length, the relief is still greater; but if we view it when inverted with the same lens the relief is very considerably diminished.

A very remarkable illusion, affecting the apparent position of the drawings of geometrical solids, was first observed by the late Professor Neckar, of Geneva, who communicated it to me personally in 1832.¹ "The rhomboid Δx ," (Fig. 51,) he says, "is drawn so that the solid

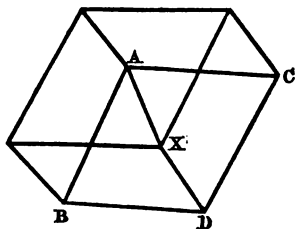


FIG. 51.

angle Δ should be seen nearest to the spectator, and the solid angle x the farthest from him, and that the face ΔCBD should be the foremost, while the face xDC is behind. But

¹ See *Edinburgh Philosophical Journal*, November 1832, vol. i. p. 334.

in looking repeatedly at the same figure, you will perceive that at times the apparent position of the rhomboid is so changed that the solid angle x will appear the nearest, and the solid angle Λ the farthest, and that the face ΛCDB will recede behind the face xDC , which will come forward, —which effect gives to the whole solid a quite contrary apparent inclination.” Professor Neckar observed this change “as well with one as with both eyes,” and he considered it as owing “to an involuntary change in the adjustment of the eye for obtaining distinct vision. And that whenever the point of distinct vision on the retina was directed to the angle Λ for instance, this angle, seen more distinctly than the other, was naturally supposed to be nearer and foremost, while the other angles, seen indistinctly, were supposed to be farther away and behind. The reverse took place when the point of distinct vision was brought to bear upon the angle x . What I have said of the solid angles (Λ and x) is equally true of the edges, those edges upon which the axis of the eye, or the central hole of the retina, are directed, will always appear forward ; so that now it seems to me certain that this little, at first so puzzling, phenomenon depends upon the law of distinct vision.”

In consequence of completely misunderstanding Mr. Neckar's explanation of this illusion, Mr. Wheatstone has pronounced it to be erroneous, but there can be no doubt of its correctness ; and there are various experiments by which the principle may be illustrated. By hiding with the finger *one* of the solid angles, or making it indistinct, by a piece of dimmed glass, or throwing a slight shadow over it, the *other* will appear foremost till the obscuring

cause is removed. The experiment may be still more satisfactorily made by holding above the rhomboid a piece of finely-ground glass, the ground side being farthest from the eye, and bringing one edge of it gradually down till it touches the point A, the other edge being kept at a distance from the paper. In this way all the lines diverging from A will become dimmer as they recede from A, and consequently A will appear the most forward point. A similar result will be obtained by putting a black spot upon A, which will have the effect of drawing our attention to A rather than to X.

From these experiments and observations, it will be seen that the conversion of form, excepting in the normal case, depends upon various causes, which are influential only under particular conditions, such as the depth of the hollow or the height of the relief, the distance of the object, the sharpness of vision, the use of one or both eyes, the inversion of the shadow, the nature of the object, and the means used by the mind itself to produce the illusion. In the normal case, where the cavity or convexity is shadowless, and upon an extended surface, and where inverted vision is used, the conversion depends solely on the illusion, which it is impossible to resist, that the side of the cavity or elevation next the eye is actually farthest from it, an illusion not produced by inversion, but by a false judgment respecting the position of the surface in which the cavity is made, or upon which it rests.

CHAPTER XVII.

ON CERTAIN DIFFICULTIES EXPERIENCED IN THE USE OF
THE STEREOSCOPE.

THERE are many persons who experience great difficulty in uniting the two pictures in the stereoscope, and consequently in seeing the relief produced by their union. If the eyes are not equal in focal length, that is, in the distance at which they see objects most distinctly ; or if, from some defect in structure, they are not equally good, they will still see the stereoscopic relief, though the picture will be less vivid and distinct than if the eyes were in every respect equal and good. There are many persons, however, whose eyes are equal and perfect, but who are not able to unite the pictures in the stereoscope. This is the more remarkable, as children of four or five years of age see the stereoscopic effect when the eye-tubes are accommodated to the distance between their eyes. The difficulty experienced in uniting the binocular pictures is sometimes only temporary. On first looking into the instrument, *two* pictures are seen in place of *one* ; but by a little perseverance, and by drawing the eyes away from the eye-tubes, and still looking through them, the object is seen single and in perfect relief. After having ceased to use the instrument for

some time, the difficulty of uniting the pictures recurs, but, generally speaking, it will gradually disappear.

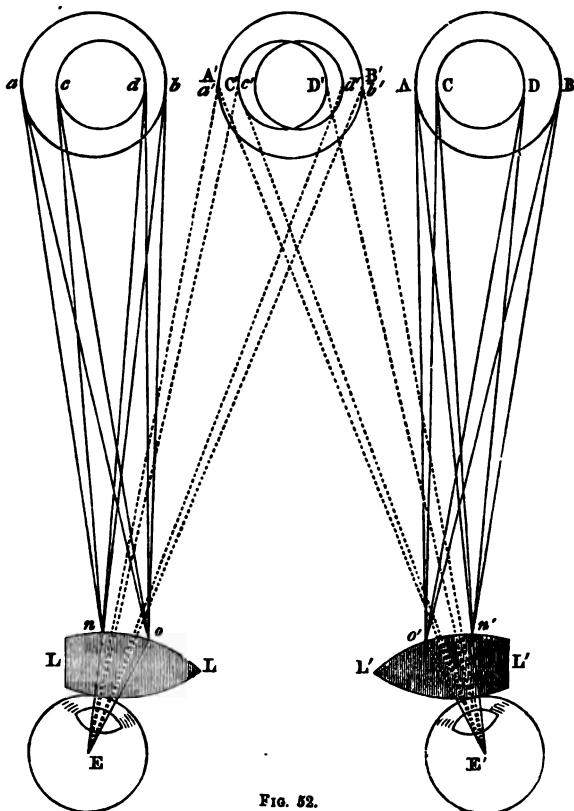


FIG. 52.

In those cases where it cannot be overcome by repeated trials, it must arise either from the distance between the lenses being greater or less than the distance between the

eyes, or from some peculiarity in the power of converging the optical axes, which it is not easy to explain.

If the distance between the pupils of the two eyes, E, E' , Fig. 52, which has been already explained on Fig. 18, is *less* than the distance between the semi-lenses L, L' , then, instead of looking through the middle portions $no, n'o'$, of the lenses, the observer will look through portions between o and L , and o' and L' , which have a *greater* power of refracting or displacing the pictures than the portions $no, n'o'$, and therefore the pictures will be *too much* displaced, and will have so far *overpassed* one another that the observer is not able to *bring them back* to their place of union, half-way between the two pictures in the slide.

If, on the other hand, the distance between the pupils of the observer's eyes is *greater* than the distance between the semi-lenses L, L' , then, instead of looking through the portions $no, n'o'$ of the lenses, the observer will look through portions between n and L , and n' and L' , which have a *less* power of refracting or displacing the pictures than the portions $no, n'o'$, and therefore the pictures will be so *little* displaced as not to reach their place of union, and will stand at such a distance that the observer is not able to *bring them up* to their proper place, half-way between the two pictures in the slide.

Now, in both these cases of *over* and *under displacement*, many persons have such a power over their optical axes, that by converging them to a point *nearer* than the picture, they would, in the first case, *bring them back* to their place of union, and by converging them to a point *more remote* than the picture, would, in the second case, *bring them up* to their place of union ; but others are very defective in

this power of convergence, some having a facility of converging them beyond the pictures, and others between the pictures and the eye. This last, however, namely, that of near convergence, is by far the most common, especially among men ; but it is of no avail, and the exercise of it is injurious when the under refracted pictures have not come up to their place of union. The power of remote convergence, which is very rare, and which would assist in bringing back the over refracted pictures to their place of union, is of no avail, and the exercise of it is injurious when the pictures have been too much displaced, and made to pass beyond their place of union.

When the stereoscope is perfectly adapted to the eyes of the observer, and the *general* union of the pictures effected, the remote parts of the picture, that is, the objects seen in the distance, may be under refracted, while those in the foreground are over refracted, so that while eyes which have the power of convergence beyond the picture, unite the more distant objects which are under refracted, they experience much difficulty in uniting those in the foreground which are over refracted. In like manner, eyes which have the power of near convergence will readily unite objects in the foreground which are over refracted, while they experience much difficulty in uniting objects in the distance which are under refracted. If the requisite power over the optical axes is not acquired by experience and perseverance, when the stereoscope is suited to the eyes of the observer, the only suggestion which we can make is to open the eyes wide, and expand the eyebrows, which we do in staring at an object, or in looking at a distant one, when we wish to converge the axes, as in Fig. 22, to a point

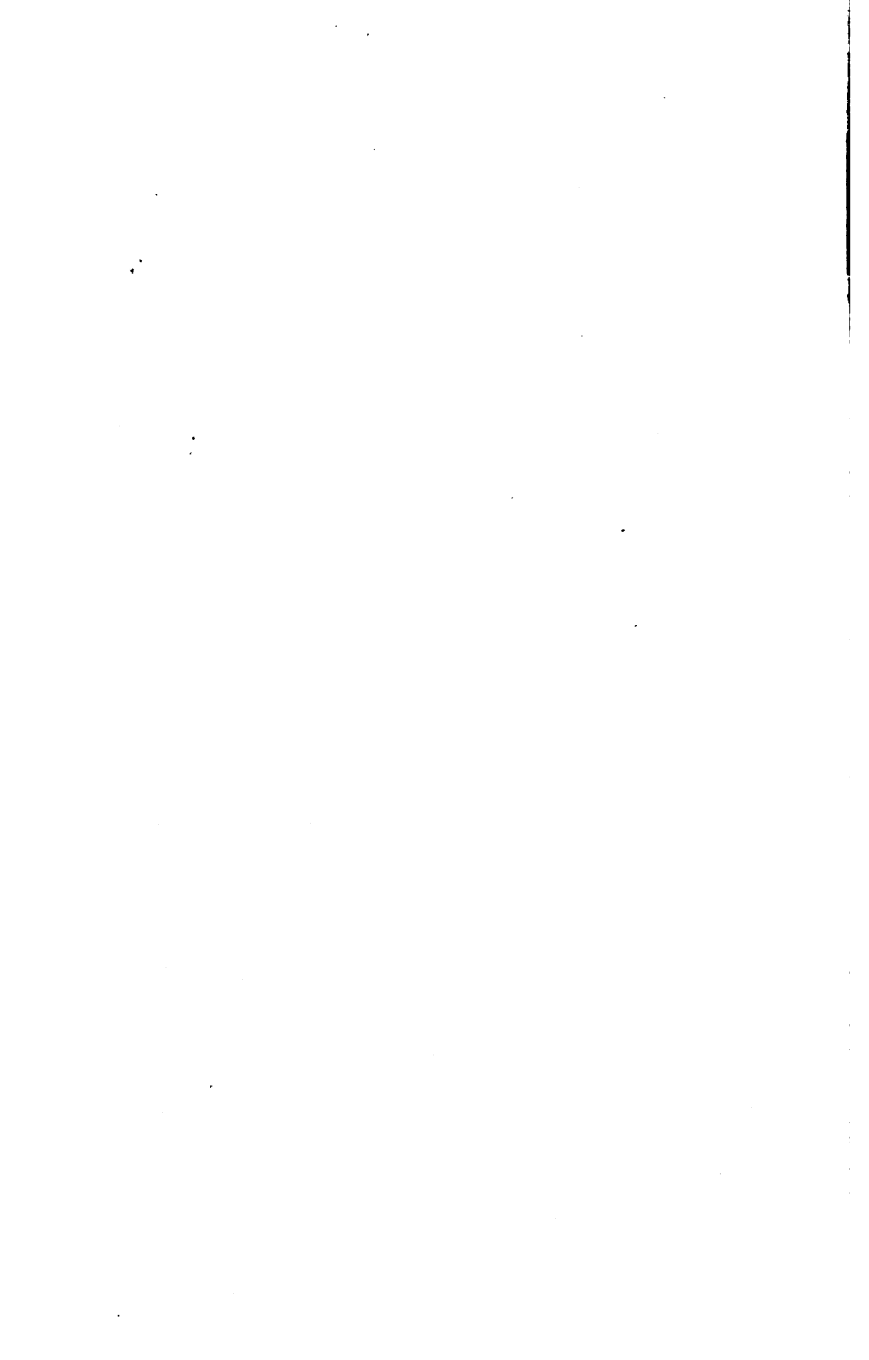
beyond the pictures, and to contract the eyes and the eye-brows, which we do in too much light, in looking at a *near* object, when we wish to converge the optic axes, as in Fig. 21, to a point *between* the pictures and the eye.

When the binocular pictures are taken at too great an angle, so as to produce a startling amount of relief, the distance between similar points in each picture, both in the distance and in the foreground, is much greater than it ought to be, and hence the difficulty of uniting the pictures is greatly increased, so that persons who would have experienced no difficulty in uniting them, had they been taken at the proper angle, will fail altogether in bringing them into stereoscopic relief.

In these observations, it is understood that the observer obtains distinct vision of the pictures in the stereoscope, either by the adjustment of the moveable eye-tubes, if they are moveable, as they ought to be, or by the aid of convex or concave glasses for both eyes, either in the form of spectacles, or separate lenses placed immediately above, or immediately below the semi-lenses in the eye tubes. If the eyes have different focal lengths, which is not unfrequently the case, lenses differing in convexity or concavity should be employed to equalize them.

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